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AIR WEATHER SERVICE
TECHNICAL REPORT 105-125

1952
ANNUAL REPORT OF TYPHOON POST-ANALYSIS PROGRAM

AUGUST 1954

HEADQUARTERS
AIR WEATHER SERVICE
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AWS TECHNICAL REPORT
NO. 105-125

AIR WEATHER SERVICE
MILITARY AIR TRANSPORT SERVICE
UNITED STATES AIR FORCE
Washington 25, D. C.

FOREWORD

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1952

FIFTH ANNUAL REPORT

OF THE

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PART I

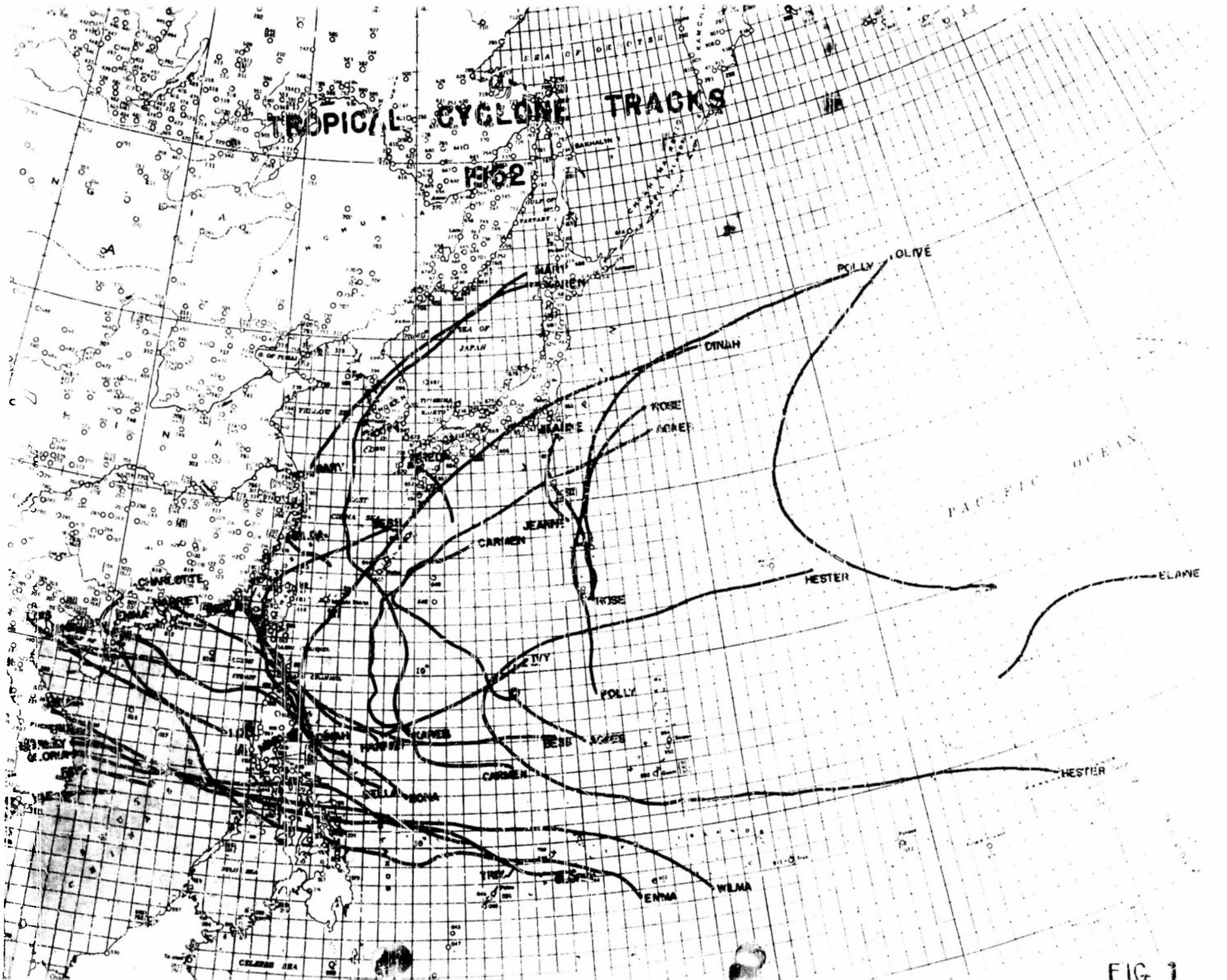
TECHNICAL

REVIEW OF THE 1952 TYPHOON SEASON

> Nature's vagaries were not so simply faced in Australia. Monsoon rains sweeping across the northern hump of Australia have created a rich patch of cattle-raising country about the size of Texas. But in the recent monsoon season (November 1951 to March 1952), for the first time in living memory, the rains did not come. Not only the northern pasture land, but the whole top half of Australia began to dry up. Within six months there was hardly a blade of grass in an area the size of Western Europe. . . . . the aborigines, who have been holding nightly rain-making ceremonial dances, gave up in despair. Government medicine man also admitted defeat, radioed northern cattle men that no relief could be expected unitl next November's monsoon (1952) - if it came.
>
> Time, May 12, 1952

Normally, outside of the monsoon regions of the southern hemisphere, the early months of the year are considered the dry season in the tropics. But "dry" is relative to tropic "wetness", which means that the "dry" season is usually not very dry according to the standards of temperate latitudes. However, the experience of cattle men in Northern Australia was similar to that of all peoples throughout the tropical Western Pacific early in 1952. While Los Angeles was recording rainfall in double figures and suffering its disastrous floods, Guam had a very serious problem of forest fires. Less than six inches of rain fell on Guam during the first four months of 1952!

In the tropical Eastern Pacific, two tropical cyclones of major proportions were detected in the area of the Fiji Islands in January and



TROPICAL CYCLONE TRACKS
1952
SEA OF OKHOTSK
SAKHALIN
GULF OF TARTARY
SEA OF JAPAN
YELLOW SEA
CHINA SEA
CELEBES SEA
PACIFIC OCEAN
POLLY
OLIVE
DINAH
ROSE
AGNES
MAMIE
MARY
KAREN
JEANNE
CARMEN
HESTER
ELAINE
IVY
BESS
CHARLOTTE
EMMA
WILMA
TRIX
NONA

FIG 1

CAUSES, STRUCTURE, AND BEHAVIOR OF TROPICAL CYCLONES OF THE NORTH PACIFIC

A. INTRODUCTION

A science may be considered to develop through four phases or periods; i.e., Descriptive, Explanative, Forecasting and Control. Academicians would have it that the Science of Meteorology has already entered phase three. However, to the typhoon forecaster responsible for a daily warning service for military installations and aircraft, Tropical Meteorology seems barely into phase one.

Accordingly, the Technical Section for this report will be again mainly couched in terms of descriptive information. The authors firmly believe that lengthy theoretical discussions at this point serve more to confuse than clarify typhoon forecasting. Enough accurate synoptic information is not yet available and thoroughly integrated to support or deny almost any mathematical theory postulated.

B. FORMATION AND DEVELOPMENT OF TROPICAL CYCLONES

A perusal of past Annual Reports shows a gradual evolution in thinking as to the origin of the tropical cyclone. This evolution is attributable largely to the influence of V. Bjerknes streamline models as applied by C. E. Palmer[1] and to the Easterly Wave Program in the Western North Pacific Ocean.[2]

Emphasis in the latter techniques is upon low level analyses and phenomena. Consolidated Reports on this year's Tropical Cyclones show that 22 out of 27 storms were immediately recognized as developments of

Analyses of charts containing winds at 14,000, 20,000 and 30,000 feet were accomplished. Streamline flow at these levels were shown. The paucity of data covering the area encompassed by typhoon development made it mandatory to maintain strict continuity from map to map. An attempt was made to explain all vertical and horizontal variations in the wind field at each available station by a logical and consistent pattern. This pattern gradually evolved into a slight modification of the Palmer application of streamlines for singularities in the wind field particularly at latitudes below 25 degrees North. 500-and 300-millibar heights were added to the appropriate charts to aid in determining whether a wind field singularity was that of a neutral point, source or sink region. Time Cross-Sections of the vertical wind field were used as particular aids in the analysis at each level.

Increasing familiarity with this type of chart led to several interesting clues about the formation and development of typhoons. All of these ideas are empirical in nature. No attempt has been made to relate these findings to dynamical formulae.

In an article on the formation of typhoons published in 1948,[5] Dr. Riehl recognized the presence of individual vortices embedded in the easterly flow at the 200 millibar level. Our data and analyses during this past season have indicated that similar vortices are also present at many levels below the 200 mb. surface. Nine, fourteen, twenty and thirty thousand foot charts show such vortices. Any unit singularity may affect only a shallow layer and be visible at only one of these levels.

easterly waves or vortices. Of the five remaining, two (ROSE and ELAINE) appear to be also from easterly waves, two (IVY-JEANNE) apparently were not true tropical cyclones, and one (GILDA) appears to be a secondary development of a preceding storm (FREDA). Elsewhere,[3] the theory is advanced that the easterly wave is a development of a vortiginous circulation already present.

C. E. Depperman in an article published in 1941[4] made the following statement: "That upper-air conditions may play an important part in typhoon formation we have no doubt, otherwise it would be difficult to explain why, with apparently almost identical surface conditions, we may in one case get a typhoon, and in the other, perhaps only a depression, or nothing." Certainly one cannot disagree with this statement. Many feel that the upper air holds the key to successful tropical forecasting.

During the season just past some empirical information on the relationship of upper level systems has been obtained. Some new ideas are suggested, which, it is hoped, will continue the evolution toward an integration of all information into a single, understandable model of tropical weather systems.

Andersen Forecast Center found it advantageous to form a separate upper air section in August 1952. This section was primarily designed for more accurate forecasting of high level winds. It so happened, however, that the Officer in Charge of the section was also a member of the Typhoon Board. This proved valuable in relating upper wind flow to the formation and development of tropical cyclones.

Analyses of charts containing winds at 14,000, 20,000 and 30,000 feet were accomplished. Streamline flow at these levels were shown. The paucity of data covering the area encompassed by typhoon development made it mandatory to maintain strict continuity from map to map. An attempt was made to explain all vertical and horizontal variations in the wind field at each available station by a logical and consistent pattern. This pattern gradually evolved into a slight modification of the Palmer application of streamlines for singularities in the wind field particularly at latitudes below 25 degrees North. 500-and 300-millibar heights were added to the appropriate charts to aid in determining whether a wind field singularity was that of a neutral point, source or sink region. Time Cross-Sections of the vertical wind field were used as particular aids in the analysis at each level.

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However, many cases will be found with vortices of sufficient vertical extent to show on more than one level. If a vortex is present in only one shallow layer, associated waves are generally present above and beneath the layer in which the vortex is embedded.

Once the existence of these wind-field singularities was established, and it was found that continuity could be maintained, such vortices continued to appear associated in some fashion with easterly waves or surface vortices which became typhoons. What is normally carried as a strong easterly wave is also generally indicated by an associated perturbation extending as high as 20,000 feet. This may be a vortex or merely a wave perturbation at the upper levels.

Fluctuations in the upper wind field over a developing surface vortex appeared frequently to be best explained by some type of dual, or double vortices, with a neutral point between. No more than two upper level vortices were noted to be associated with one surface perturbation, and they most often appeared to be oriented in a North-South direction. Occasionally the orientation appeared to be East-West.

In the case of typhoon OLIVE considerable additional work was done in studying the wind field relating to the development. All available wind data from aircraft and upper air soundings were used. The best analysis of the 9000 foot wind field at or near the time of the most rapid development is shown in Figures 2 through 5. This N-S double vortex was noticed also, particularly in the incipient stages, with ELAINE, FAYE, DELLA, WILMA, TRIX, and HESTER.

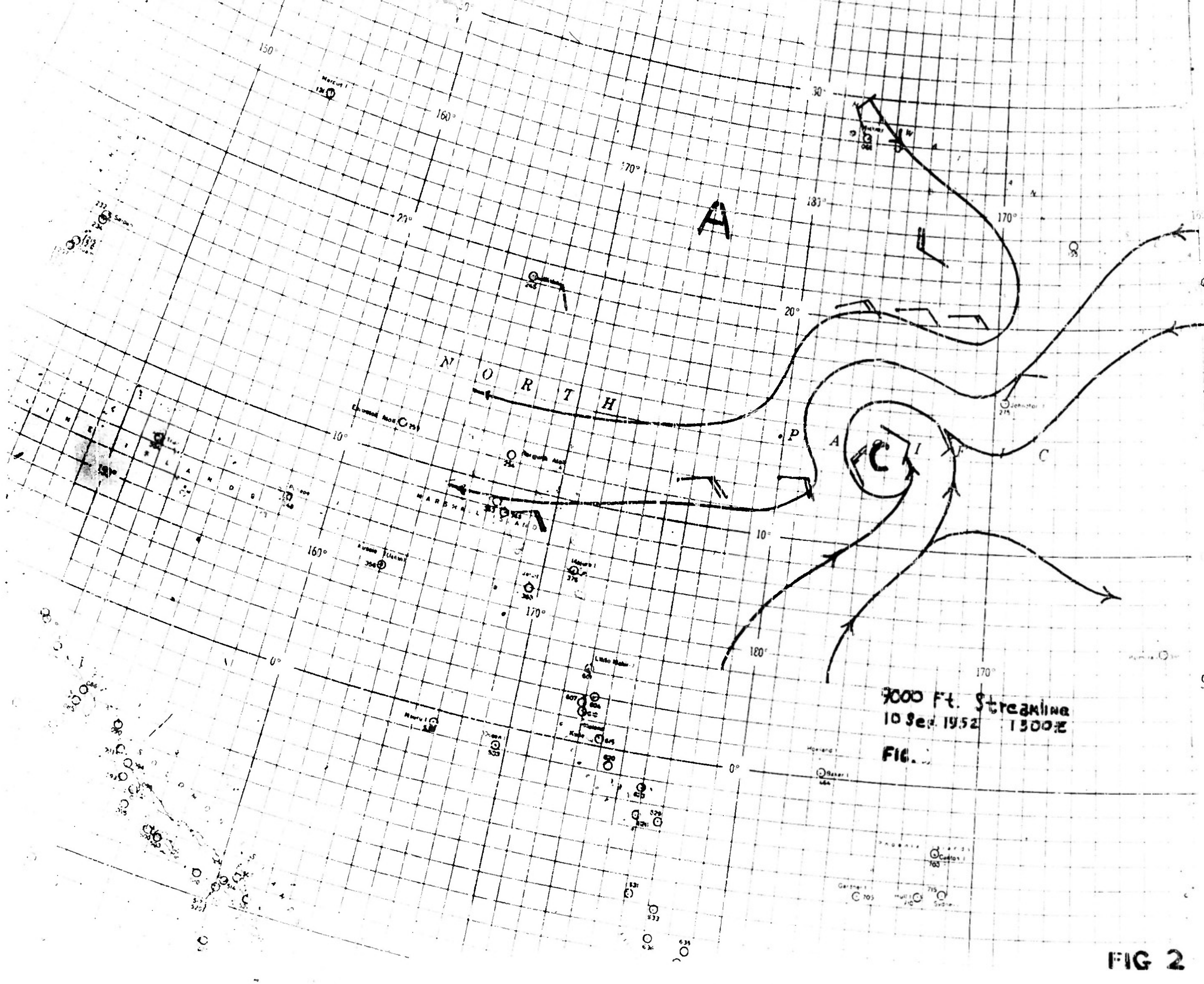

A
NORTH
PACIFIC
C
MARSHALL ISLANDS
9000 Ft. Streamline
10 Sep. 1952 1500Z
FIG.

FIG 2

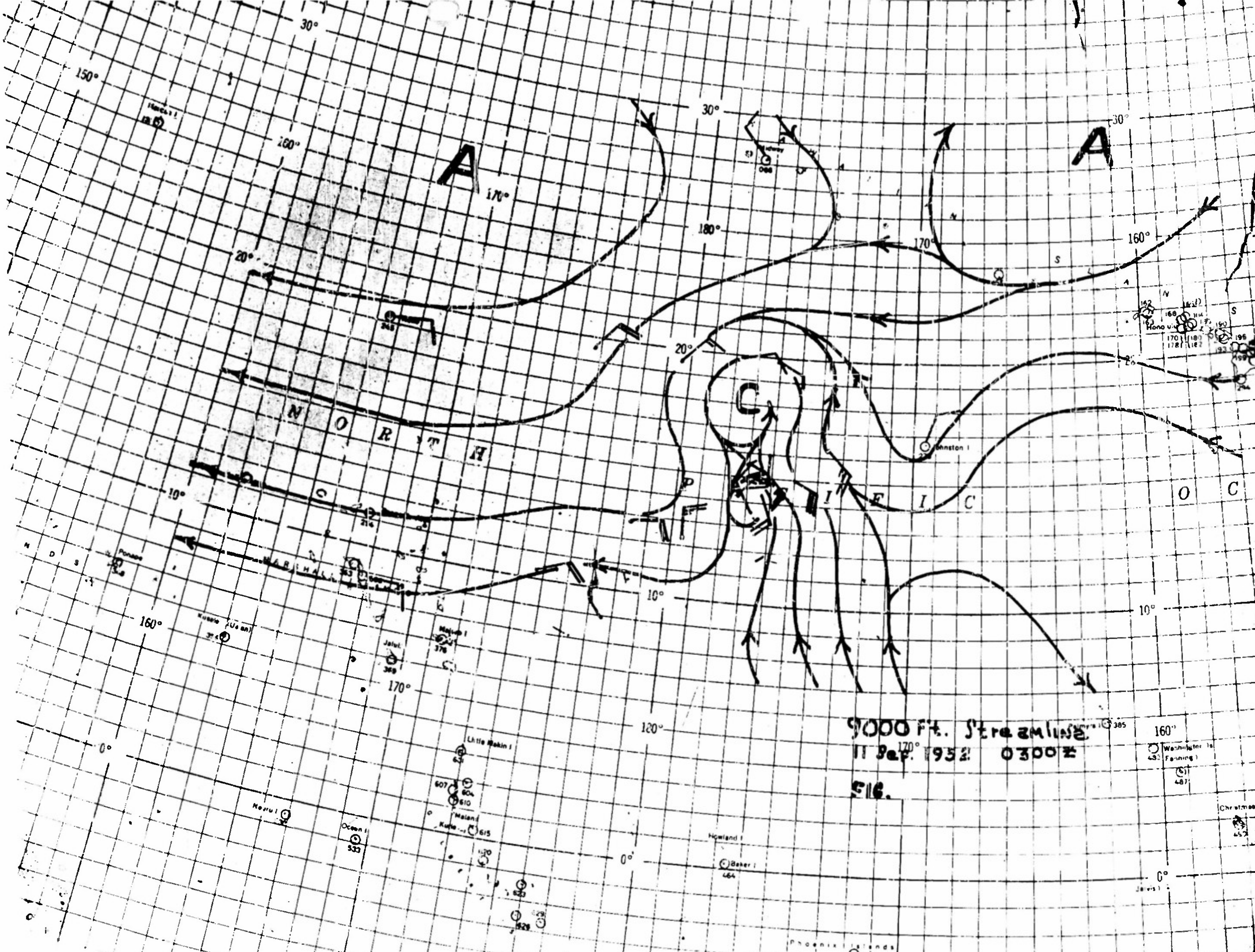
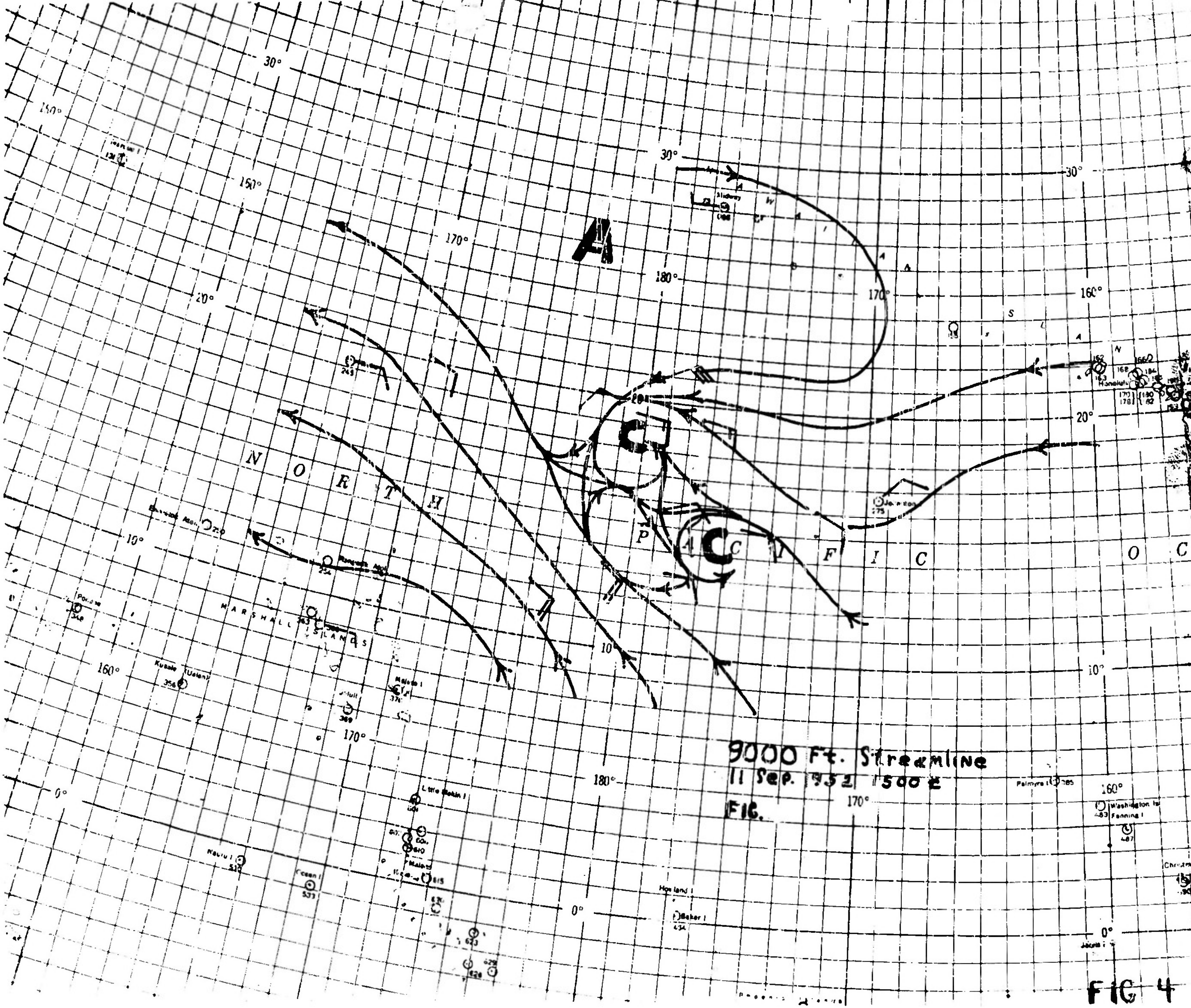
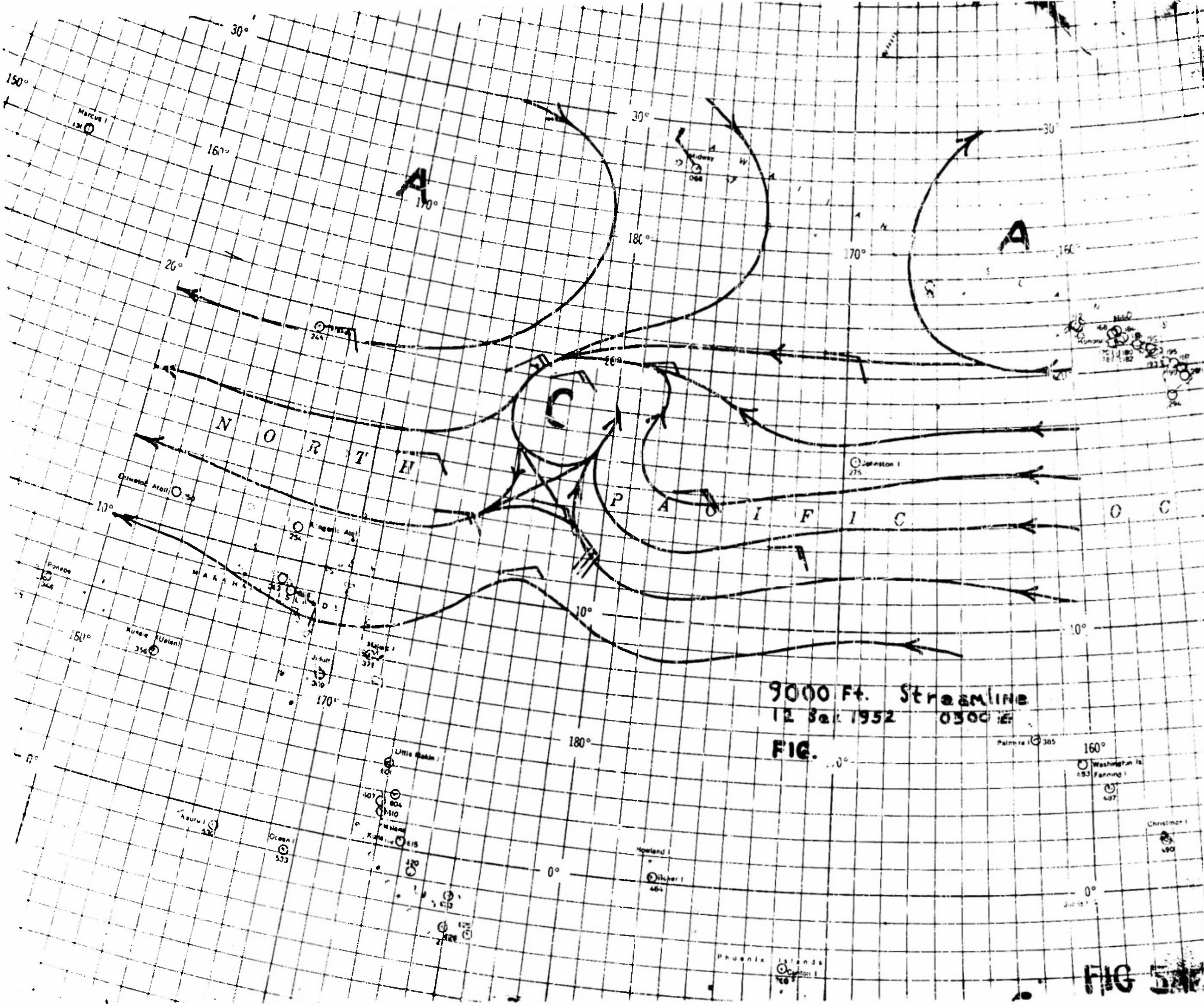

9000 Ft. Streamline
11 Sep. 1952 0300Z
FIG.
A
A
C
NORTH
PACIFIC
OC
MARSHALL
Johnston I
Little Makin I
Howland I
Baker I
Christmas I
Washington Is
Fanning I
Jarvis I
Phoenix Islands
Ocean I
Nauru I
Jaluit
Majuro I
Ponape
Kusaie (Ualan)
Hono

FIG 5



9000 Ft. Streamline
11 Sep. 1952 1500 Z
FIG.
A
C
C
P
N O R T H
P A C I F I C
O C
MARSHALL ISLANDS
Honolulu
Midway
Johnston
Palmyra I
Washington Isl
Fanning I
Christmas
Howland I
Baker I
Nauru I
Ocean I
Kusaie (Ualan)
Ponape
Majuro I
Little Makin I

FIG 4



9000 Ft. Streamline
1952
FIG.
N O R T H P A C I F I C O C E
Marcus I
Midway
Johnston I
Ponape
Kusaie (Ualan)
Majuro I
Jaluit
Little Makin I
Ocean I
Howland I
Baker I
Palmyra I
Washington Is
Fanning I
Christmas I
Phoenix Islands
Canton I

FIG 5A

In addition to the wind field analysis of the streamline chart, a careful thermal analysis was added for the 500 and 300 mb temperatures. This analysis included the use of shear vectors for isotherm orientation at individual stations. The shear vector was determined by the vertical change in wind between levels surrounding the 20,000 and 30,000 ft charts. Specifically, the shear between 16 and 25,000 feet was used on the 20,000 foot chart and the shear between 25,000 and 35,000 feet for the 30,000 foot chart.

This thermal analysis has also contributed some information on typhoon development. It was observed that the original surface vortex came under the influence of a pocket of air aloft colder than its surroundings at 20,000 and 30,000 feet prior to the development, in addition to a double vortex. Once typhoon intensity was reached, however, the air over the storm immediately became warm relative to the surrounding atmosphere.

The mechanism involved in typhoon development when related to these upper air vortices has not been thoroughly evaluated. Some qualitative explanations can be suggested:

1. Twin vortices when close enough to each other may show a rapid Fujiwhara rotation,[6] and coalesce and deepen into one system. This mechanism was indicated in the case of OLIVE[7].

2. The neutral point between two adjoining vortices can be considered as an area of mass divergence. This may then be the divergent area aloft under which a surface vortex is theoretically required to move before intensification can take place.

It must be pointed out that this is not considered to be the only mechanism which may lead to the development of the tropical cyclone. Because of the wide gaps in data in tropical regions, small bits of information must be gleaned from each situation in which reporting stations are properly located relative to the storm areas. The evidence obtained from the ELAINE-FAYE situation[8] strongly indicates that the upper air singularities are not in themselves enough for the development and maintenance of a strong stable vortex or typhoon.

The upper level double vortex idea appears to be a new thought as far as the Board is able to determine. Such an idea may be implied in the statement of Riehl's in the Compendium of Meteorology[9] on tropical systems, where he states: "If a storm is situated as described above, it will be flanked by other vortices east, west, south, and frequently even north especially in the upper troposphere. A mean zonal motion does not exist at high levels. Attempts at forecasting must turn to the relation between the upper vortices."

Actual evidence of North-South oriented double vortices have been found within a height trough in northern latitudes this year on Petrel flights from Hawaii and Buzzard flights from Yokota.

C. MOTION OF TROPICAL CYCLONES

Deductions in Meteorology are always dangerous. Invariably the indicated deduction is made on a period of time too short to be truly representative of the total years in which terrestrial weather has existed. The authors will definitely be guilty of this by suggesting

that the danger areas for tropical cyclone development can always be detected by proper use of the Easterly Wave Program and upper air streamline charts. Yet the past season indicated this.

Once a suspicious area was recognized synoptically, an aerial reconnaissance aircraft was dispatched to verify the indications and follow the developing storm. Rarely, did any system develop which had not been previously anticipated.

After a storm or typhoon has been detected, the typhoon forecaster's problems multiply. He must decide where the storm is, within one tenth of one degree of latitude and longitude, and forecast the 24 hour movement within the same limits. He has two aids: reconnaissance fixes and synoptic situation. If the time of fix occurs near the valid time of the bulletin, or the storm is affecting one or more reporting stations, the problem of location is relatively simple. If, however, no fix has been received for the previous 12-18 hours and no reporting stations are near the storm track, then a proper determination of the system's motion is all important. Add to this uncertainty the requirement of a 24 hour forecast, and the typhoon duty forecaster seems almost to be groping in the dark.

In recognition of this problem the pages written in past Typhoon Annual Reports on the movement of tropical cyclones outnumber those written on the formation and development of such systems. Likewise, in the limited sampling of technical publications available to the Board, a similar trend is noticeable.

Unfortunately, most of the forecasting rules which have been deduced were developed from post analysis studies and are therefore subjective in nature. In general, none is sufficiently objective and quantitative to be valuable in the day-to-day requirements of the duty forecaster. For example, several past Annual Reports have carried typical upper air flow patterns which cause tropical cyclone recurvature. These are very good as far as they go. But it is difficult and even impossible to draw an upper air analysis based on one station for every 700 miles which can accurately indicate depth and intensity of a system, without some additional objective information.

The authors of the 1949 Annual Report point out: "Because of the lack of data at higher levels in the Pacific, the 700 mb chart is most often used to estimate the steering current. Naturally this sometimes leads to erroneous forecasts, as with Typhoons PATRICIA and ALLYN, who were both forecast to recurve in advance of westerly troughs in the vicinity of 135 degrees East longitude. Neither did so because the troughs were not as deep as they appeared on the 700 mb charts. On the other hand the troughs that finally caused both of these storms to recurve did not appear sufficiently deep on the 700 mb chart to effect such recurvature."[10] The same problem has been experienced during this season.[11] It will be the prupose of this section to indicate a possible objective method by which recurvature can be forecast more accurately. As yet, the proposed method is a post analysis development and may be subject to some of the objections already mentioned. It is unfortunate that time

has not permitted testing the method in actual day to day forecasting before this report is due. Nevertheless, the concept is believed to be of sufficient value to warrant reporting.

Elsewhere we have included a climatology study dividing past typhoons into several classes or types by means of their development region and track. For purposes of this section we shall further simplify this. Roughly, we can divide all storms into two classes, one in which the cyclone moves in a more or less straight and/or slowly curving path in a WNW direction from beginning to end, and a second class in which the path shows marked deviation from such a track. This latter phenomenon is generally accorded the name "recurvature". Actually the term recurvature is a misnomer so it is well to define exactly the meaning assigned it herein. For the purposes of this report, therefore, recurvature is defined to refer not only to a "major alteration of a storm track",[12] but also to any storm track which has taken on an easterly component, even though the change may be too gradual to apply the term "major alteration".

The advantage to the forecaster of this simplified classification is immediately apparent. The first class can be very accurately forecast by use of either plan extrapolation or modified extrapolation which takes into account slight changes in direction.[10] The second class can be forecast by extrapolation until recurvature is indicated and appropriate modification made to allow for the alteration of direction. The difficulty then is in deciding when recurvature is indicated.

The probability exists that recurvature prior to or at the longitude

of Okinawa can be forecast by using a graph of the 500 mb temperature at this station. Graphs of the 500 mb temperatures and heights over Okinawa and Iwo Jima have been prepared for the 1952 typhoon season. Winds at 500 mb have also been included. It is readily apparent that the temperature change is more representative of the strength of a trough than is the height change or wind shift shown at Okinawa. The change in temperature appears much more indicative of probable recurvature than does the change in height. This is further evidence of the empirical data which indicate that the height of the base of the westerlies and/or the westerly wind component over tropical or subtropical regions can be closely correlated to the depth of the temperature trough aloft at stations to the north.[13]

Portions of the graph are reproduced herewith as Figures 6 and 7. Inspection of Figure 6 which contains the temperature and height traces during the period of TRIX and WILMA shows that very warm air moved in at 500 mb over Okinawa. Except for minor fluctuations of 1 to 1.5 degrees the temperature slowly rose throughout most of the existence of TRIX, and slowly fell during WILMA. No recurvature occurred.

Conversely, the traces on CARMEN and DELLA in Figure 7 show the appearance of the curves prior to the recurvature of each typhoon. Generally, if the temperature change at 500 mbs is greater than minus 1.5 degrees at Okinawa, and does not warm up to the former value within 12 hours, this cold air will lead to a recurvature of the storm path. The storm must be in the sector approximately bounded by 10 N and 20 N,

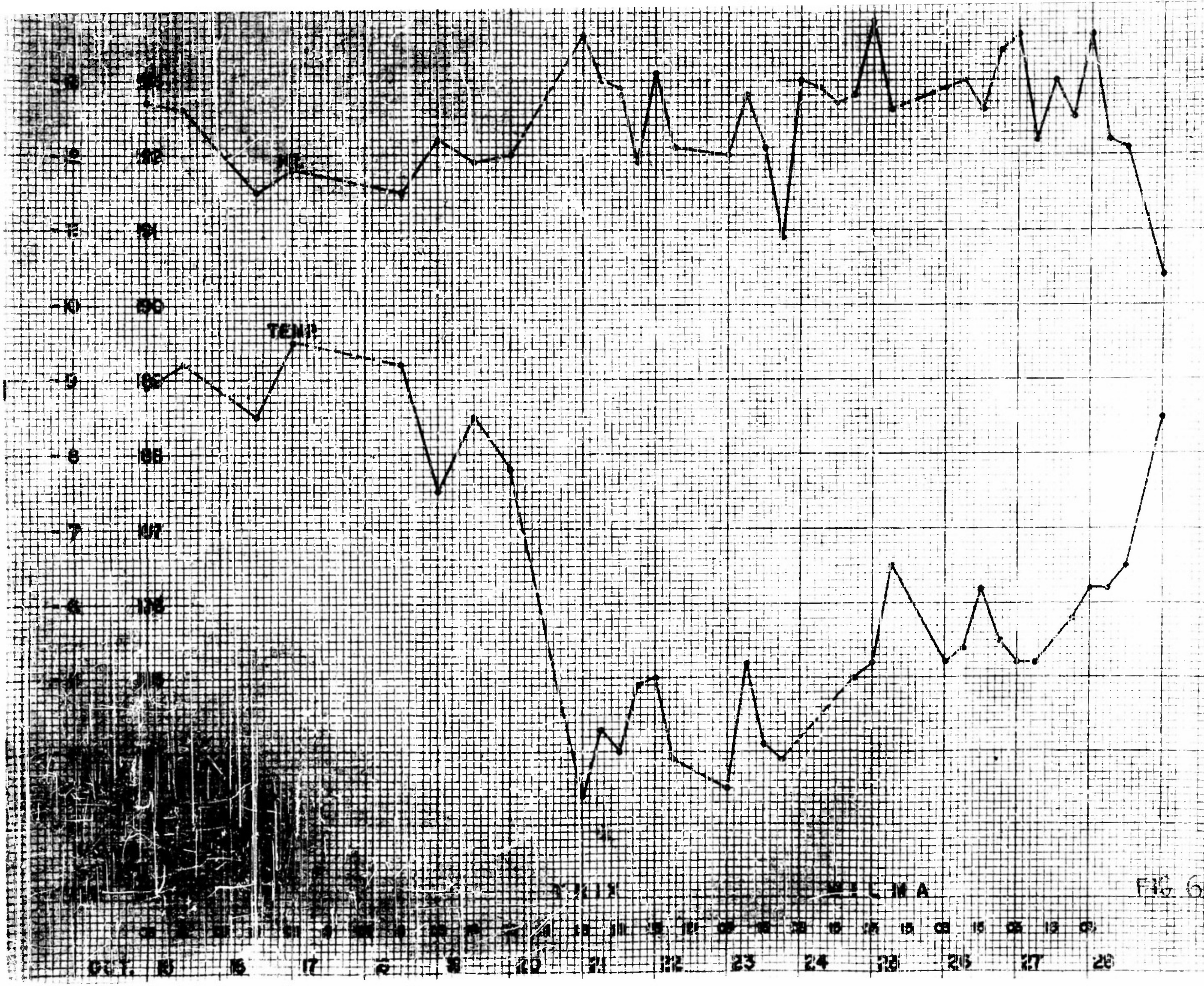


FIG. 6

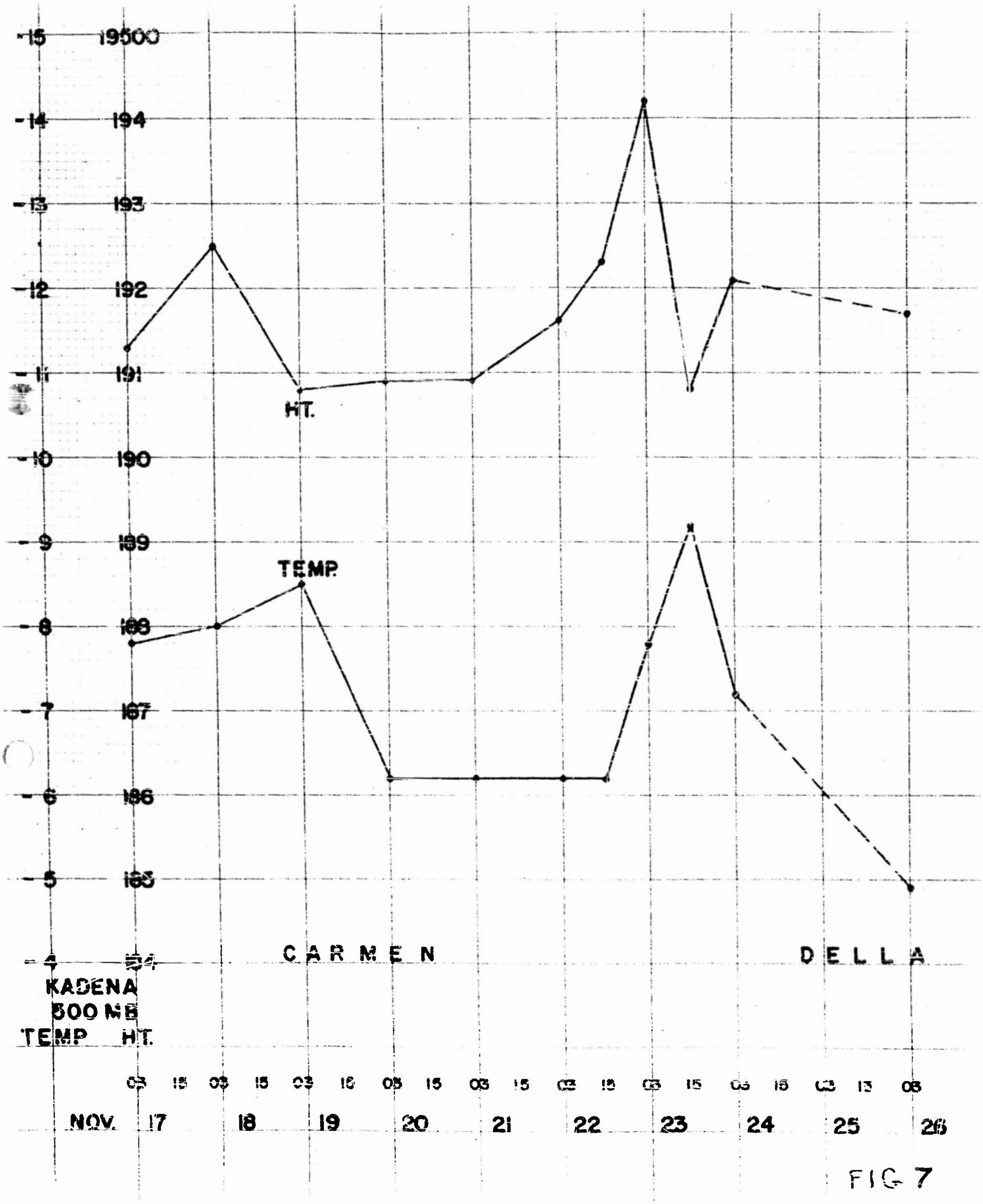

-15 19500
-14 194
-13 193
-12 192
-11 191
HT.
-10 190
-9 189
TEMP.
-8 188
-7 187
-6 186
-5 185
-4 184
CARMEN
DELLA
KADENA
500 MB
TEMP HT.
03 15 03 15 03 15 03 15 03 15 03 15 03 15 03 15 03 15 03
NOV. 17 18 19 20 21 22 23 24 25 26

FIG 7

and 132E and 122E to be affected. It is expected that the addition of the Hong Kong reports will aid in forecasting recurvature of storms west of Okinawa. The same relationship of 500 mb temperature and storms southeast of Iwo Jima is also apparent in POLLY, WILMA, and HESTER. Abruptness of recurvature is determined by the location of the storm relative to the axes of the upper level anticyclones and the depth of the temperature trough crossing Okinawa. The closer the center is to the westerly flow, the smaller the temperature change necessary to bring the westerlies down to the storm track.

The Board feels that this method of forecasting recurvature is of value, and intends to test it objectively during the 1953 season. By watching the upper air temperature changes at stations to the northwest of the typhoon track it is possible to forecast the lowering of the base of the westerlies ahead of the storm. Only by additional experience with this method can the exact relationship be determined between the depth of the cold air and the time taken for the base of the Westerlies to work down to the latitude of the storm. Too few storms have been observed so far to obtain this information since the ideas herein have mainly been developed on postanalysis.

No discussion of a proposed objective forecasting method for recurvature would be complete without verifying its application to typhoon AGNES of Oct-Nov 1952.[14] This storm developed typhoon intensity within 24 hours after passing Guam. It proceeded on a smooth track of about 300 degrees for another 24 hours, decelerated and started to recurve.

This attempted recurvature failed when the storm completed a loop and continued heading directly for Okinawa. After one more minor irregularity in the track the storm appeared to be certain of striking the island with full force, only to abruptly recurve to the NE within 120 miles of the base.

A study of the 500 mb temperature trace at Okinawa shows that a temperature drop of over 3 degrees occurred 36 hours in advance of the closest approach of AGNES to the island. No information as to the speed of this temperature trough is known in the absence of data farther to the West. To be the trough into which AGNES recurved the cold air would have had to be moving about 5 knots. A normal speed between Okinawa and Iwo Jima has been noted to be nearer 15-20 knots. In this case recurvature would have been forecast to occur about 300 miles East of where it did. It remains to be seen whether experience with this forecasting tool will lower this error. It is encouraging to note, however, that the recurvature which did take place was indicated in postanalysis by the 500 mb temperature trace.

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CLIMATOLOGY

With the objective of improving the climatological approach to forecasting the movement of tropical cyclones an attempt has been made to classify tropical cyclones into individual types or classes without regard to the month.

The paths of all tropical storms and typhoons from 1945 thru 1952 were divided into five classes and entered on the appropriate charts. After the paths were entered it was apparent that some of the classes could be further sub-divided. Figure 8 shows the mean track of each class and sub-class.

When all the paths of the eight year period were entered it was noticed that several of the tracks could have been classified as belonging to more than one class and that there was considerable individual interpretation as to just what class a few of the tropical cyclones belonged.

This is understandable in view of the erratic and sometimes unpredictable paths that many tropical storms and typhoons follow.

The 158 tropical storms and typhoons on which research was done were separated into the following classes.

CLASS I:

Class I represents 26.6% of all the tropical storms and typhoons reported during the past eight years. They are the

tropical storms and typhoons that develop between the Eastern Caroline and Marianas Islands and move west-northwestward, recurving generally between 15° N and 25° N and between 140° E and 125° E.

This class is sub-divided into 1A and 1B. Sub-class 1A recurves east of 130° E and in the majority of cases passes south of Japan. Sub-class 1B recurves west of 130° E and in the majority of cases passes thru the Ryukyus and over Japan.

CLASS 2:

These tropical storms and typhoons generate in the Caroline Islands or in the region between the Eastern Caroline and Marianas Islands. They move on a west to northwesterly course and pass over or near the Philippines. This class is sub-divided into three sub-classes which are 2A, 2B, and 2C.

Sub-class A consists of tropical storms and typhoons that generate in the Caroline Islands and move on a west to northwest course passing thru the central Philippines and usually moving inland between Hainan Islands and Hong Kong.

Sub-class B develops between 10° N and the southern Marianas. They move almost parallel to 2A and pass near or over Formosa. From here they move over the eastern coast of China, into the Yellow Sea, over Korea, then into the Sea of Japan where they dissipate.

Sub-class C develops in the same area as 2B and usually pass a short distance south of the southern tip of Formosa and

thence into Southern China.

Class 2 comprises 28.6% of the total number of tropical storms and typhoons. This class contains the largest percentage of all the tropical storms and typhoons.

CLASS 3:

This class develops in the Central Caroline Islands and moves on a west-northwesterly course passing thru the northern half of the Philippines. It makes up 15.2% of the total.

Class 3 is sub-divided into sub-classes 3A and 3B.

Sub-class 3A passes thru the Central Philippines and moves nearly straight westward to the French Indochina coast.

Sub-class 3B moves over Luzon and recurves sharply, passing between Northern Luzon and Formosa. From there they move on an east-northeasterly course passing thru the Ryukyus and dissipate well south of Japan.

CLASS 4:

This class consists primarily of tropical storms and typhoons that spend most of their life east of 140° E and occur 14.9% of the time.

Recurvature in this class generally occurs at a higher latitude than in the previous classes with the possible exception of sub-class 3B. The mean track of this class is of little significance since there is great variation in the individual tropical storm and typhoons.

CLASS X:

Into this class have been placed all erratic paths that could not be clearly classified by any of the previous classifications. As in most of the other classes it is possible to reclassify some of the tracks. In actual practice, however, this would be of little consequence since the controversial tracks vary considerably from the mean track. Class X systems have been and will continue to be difficult to forecast. They are included primarily to account for the balance of tropical storms and typhoons. The fact that systems in this class occur 16.7% of the time is important since the forecaster can anticipate three to four systems of this class will develop in a "normal" year.

Figure 14 shows the months of the year that each of these classes and sub-classes is most likely to occur, also the percentages and mean values of each type are given.

STATISTICAL STUDY FOR 1945 THRU 1952

A study has been made of all the tropical storms occurring during the years 1945 thru 1952. These years were used for two reasons: First, data were available at the Typhoon Warning Center for these years and secondly, data obtained during these years were obtained by the same type reconnaissance, same branch of the service, and by personnel with similar qualifications.

These results of 1945-1952 seasons are compared with the results of 38 seasons described in the publication "Weather and Climate of China" Report No. 890, Weather Division, Hq. AAF, March 1945.

Figure 17 shows the close similarity among the seasonal distribution of the selected periods.

During the 38 year period the mean number of systems which are assumed to be tropical storms and typhoons is 22.3 per year. For the 1945-1952 period the mean is 21.0 per year.

Since 27 named systems were accounted for in Typhoon Bulletins during 1952, it would appear at first that the 1952 season was the most active in the past eight years.

This is not necessarily a fact since upon closer examination it can be easily shown that IVY and JEANNE could or should have been carried as one system. The tropical storms named FRED., GILDA, and SHIRLEY could have been entirely disregarded as far as accomplishing the mission of the Typhoon Warning Center is concerned. Typhoons ELAINE and FAYE were actually of the same system and could therefore

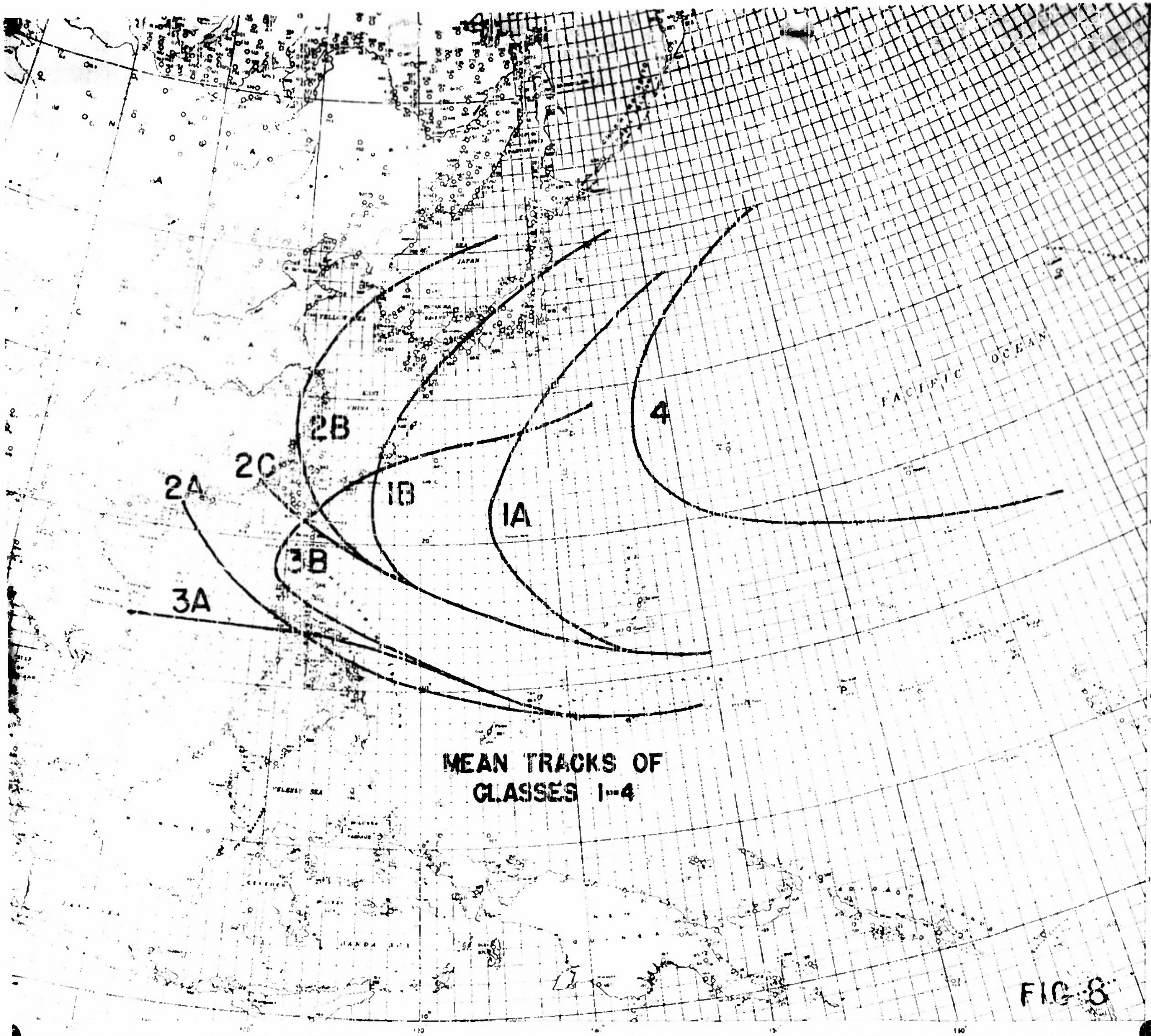
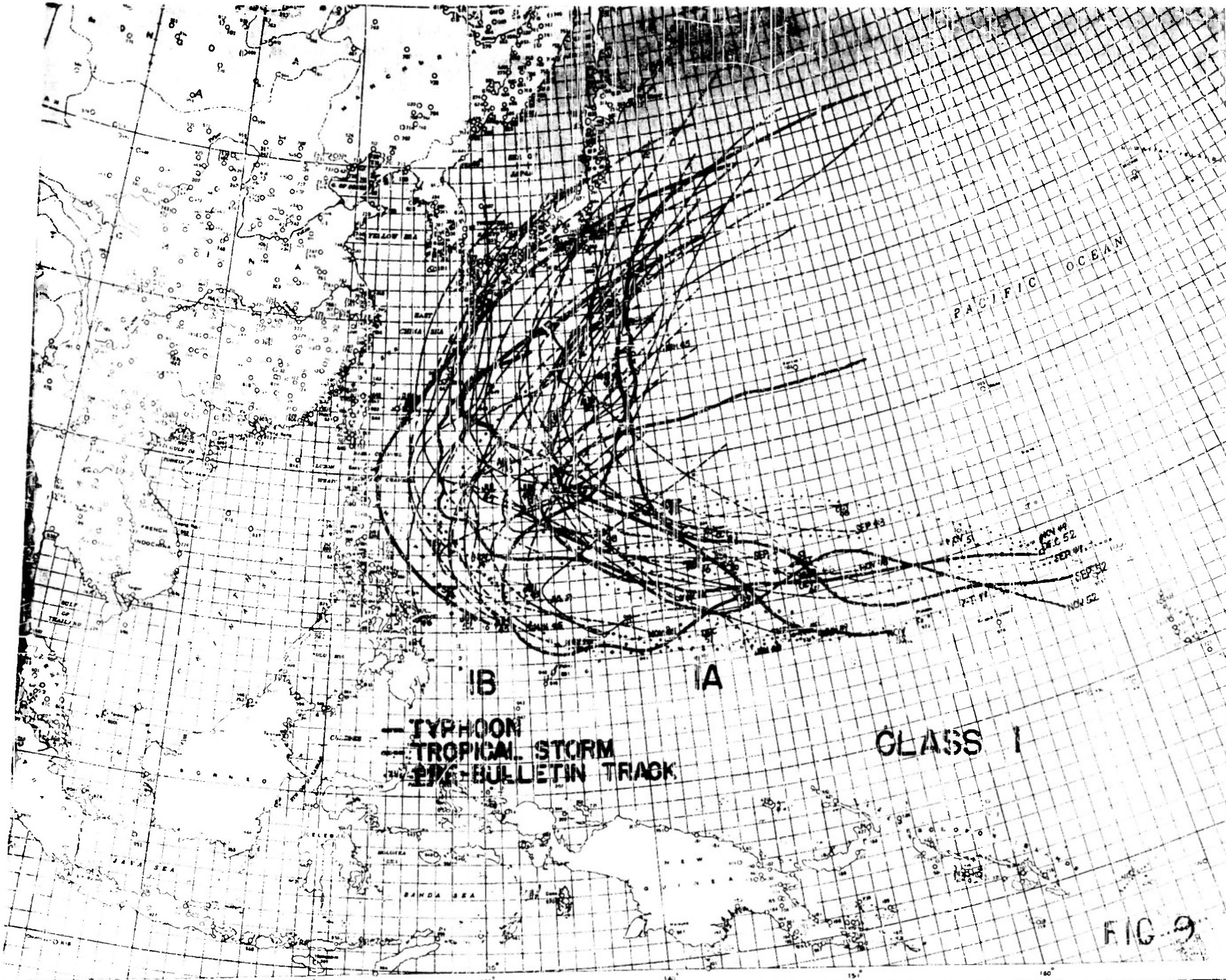

2B
2C
2A
1B
1A
4
3B
3A
PACIFIC OCEAN
JAPAN
MEAN TRACKS OF
CLASSES 1-4

FIG. 8


PACIFIC OCEAN
YELLOW SEA
EAST CHINA SEA
FRENCH INDOCHINA
GULF OF TAILAND
JAVA SEA
BANDA SEA
NEW GUINEA
BORNEO
IB
IA
CLASS I
— TYPHOON
-- TROPICAL STORM
BULLETIN TRACK
SEP 53
NOV 52
SEP 52
DEC 52
FIG 9

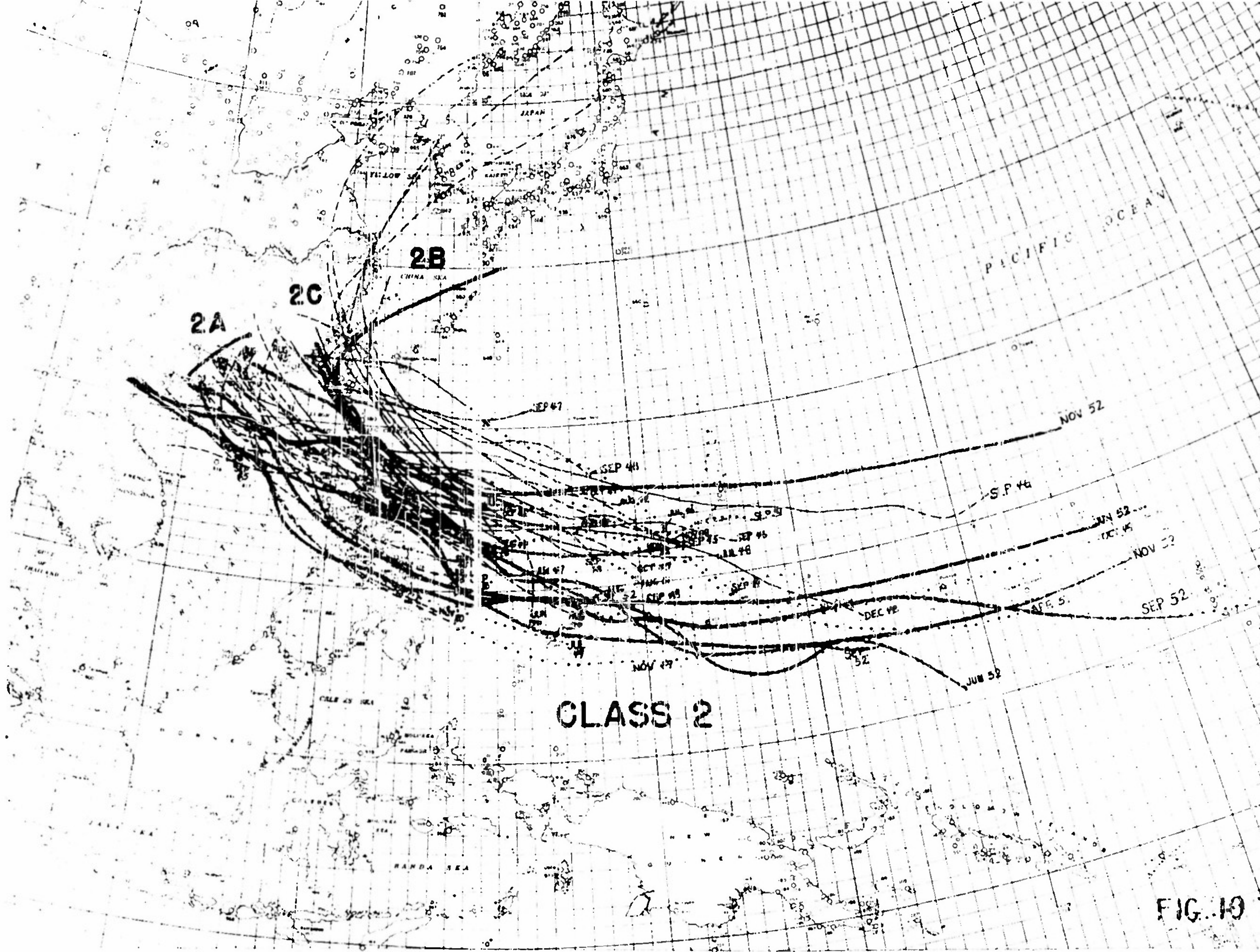
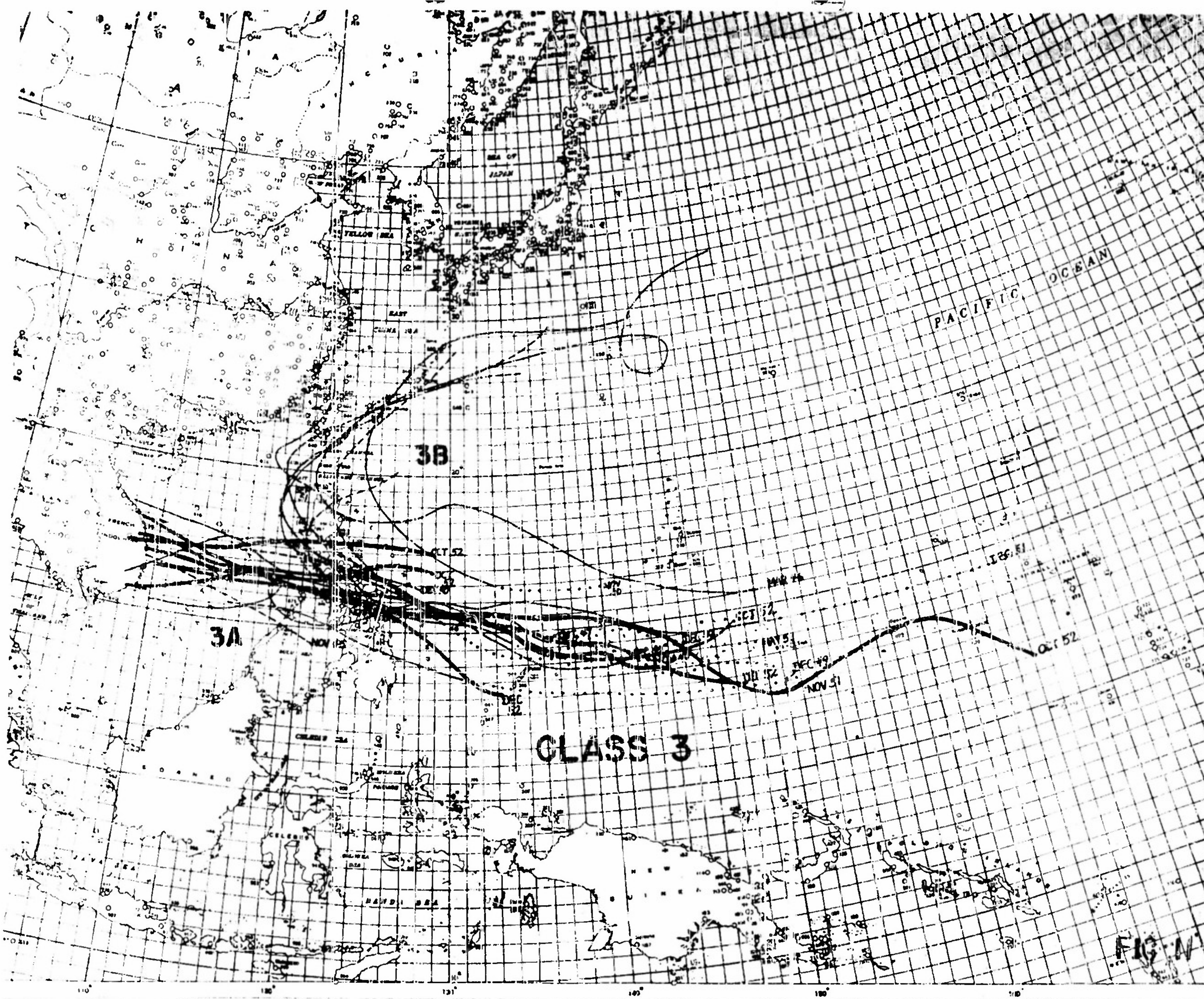
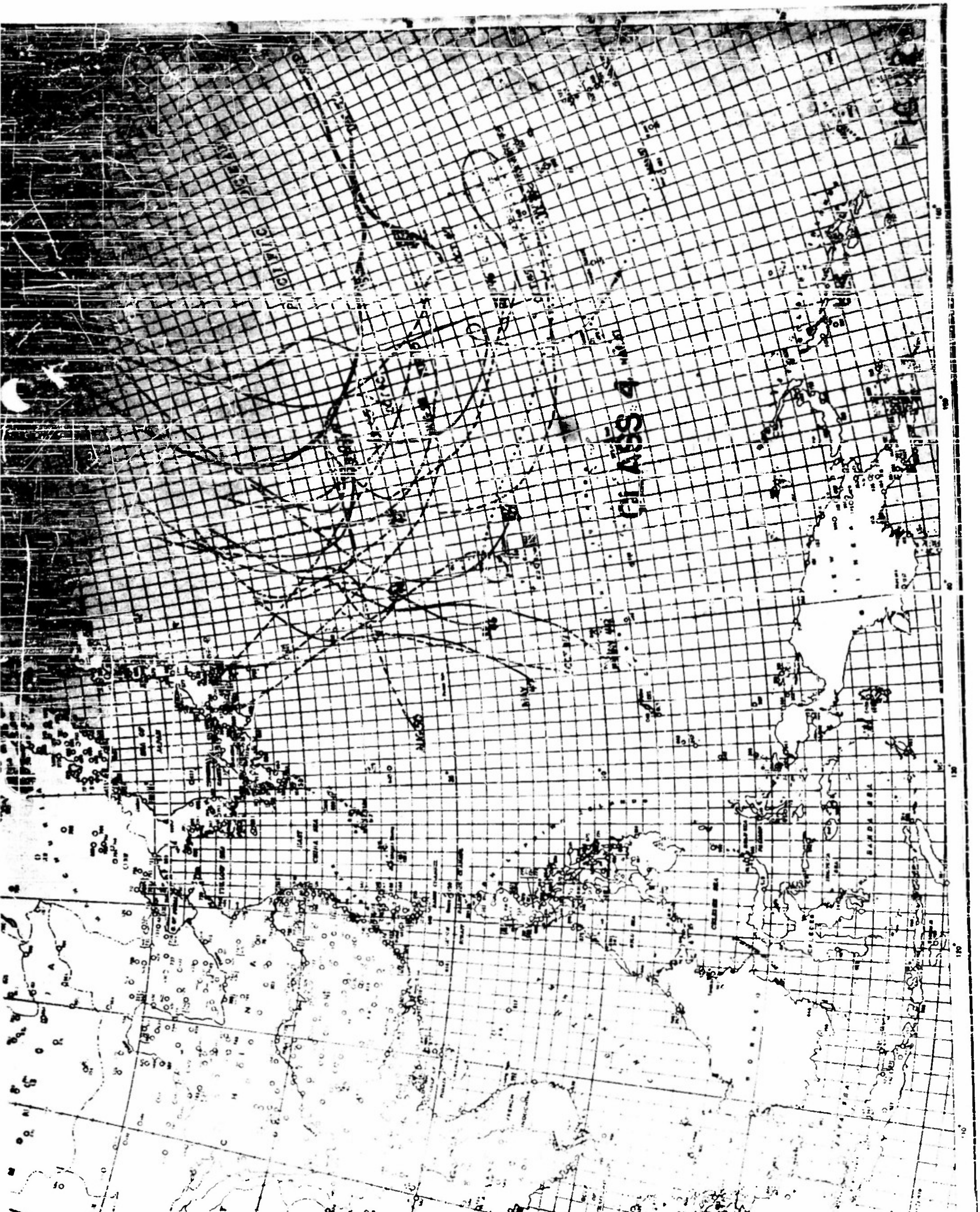

PACIFIC OCEAN
2A
2B
2C
CHINA SEA
JAPAN
BANDA SEA
NOV 52
SEP 47
SEP 48
S.P 46
JUN 52
NOV 52
SEP 52
DEC 48
JUN 52
NOV 47
CLASS 2

FIG. 10


PACIFIC OCEAN
SEA OF JAPAN
YELLOW SEA
EAST CHINA SEA
CELEBES SEA
BANDA SEA
JAVA SEA
NEW GUINEA
3A
3B
OCT 52
DEC 51
MAY 46
OCT 52
NOV 51
DEC 49
DEC 52
NOV 51
CLASS 3
FIG. IV



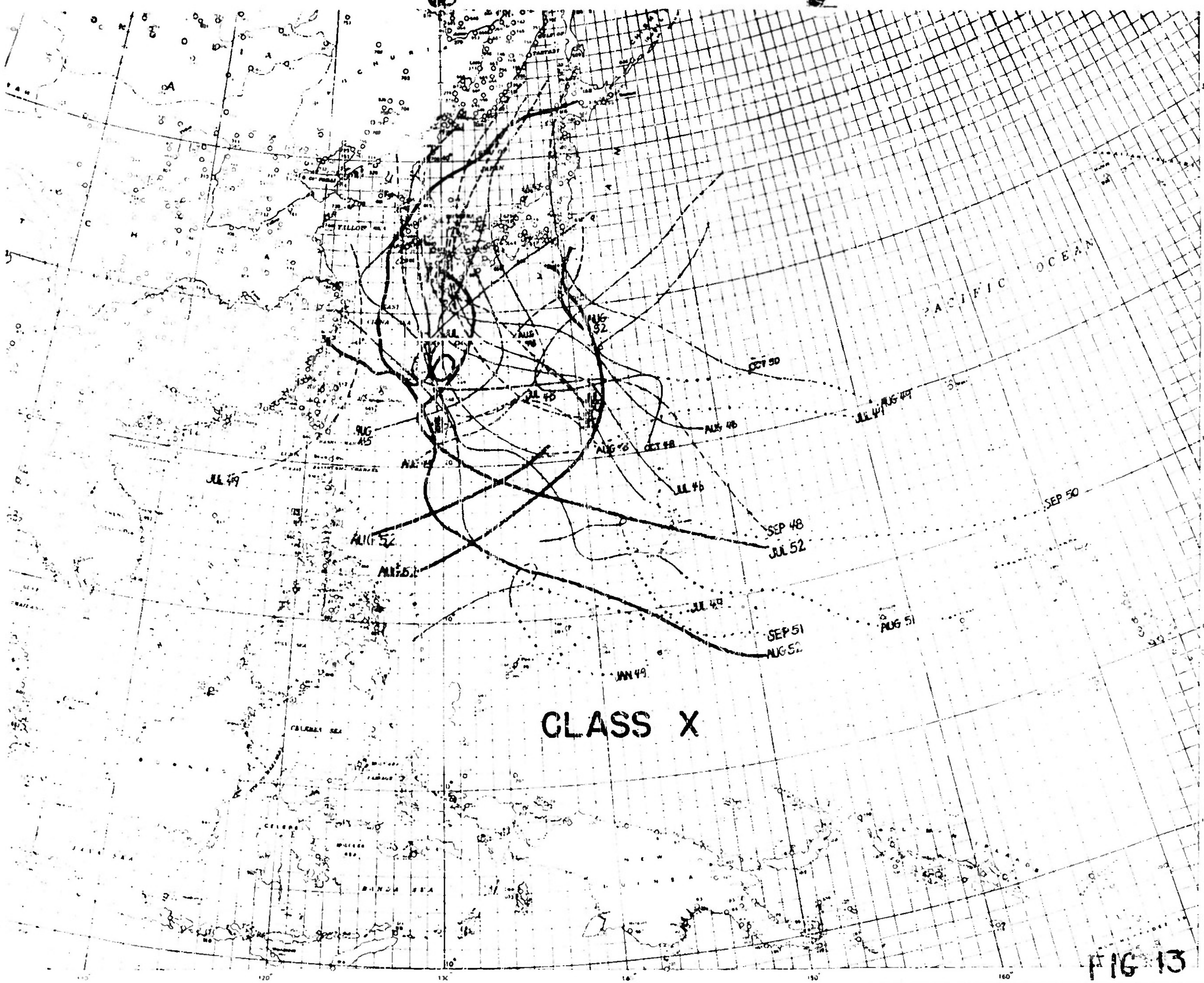

CLASS X
PACIFIC OCEAN
OCT 50
JUL 49
AUG 49
AUG 48
OCT 48
AUG 46
JUL 46
SEP 50
SEP 48
JUL 52
JUL 49
AUG 51
SEP 51
AUG 52
JAN 49
AUG 52
AUG 51
AUG 45
JUL 49

FIG 13

have been carried under one name. With these deletions a total of 22 systems could be accredited to the 1952 season which could make the season normal in the number of systems but abnormal in distribution.

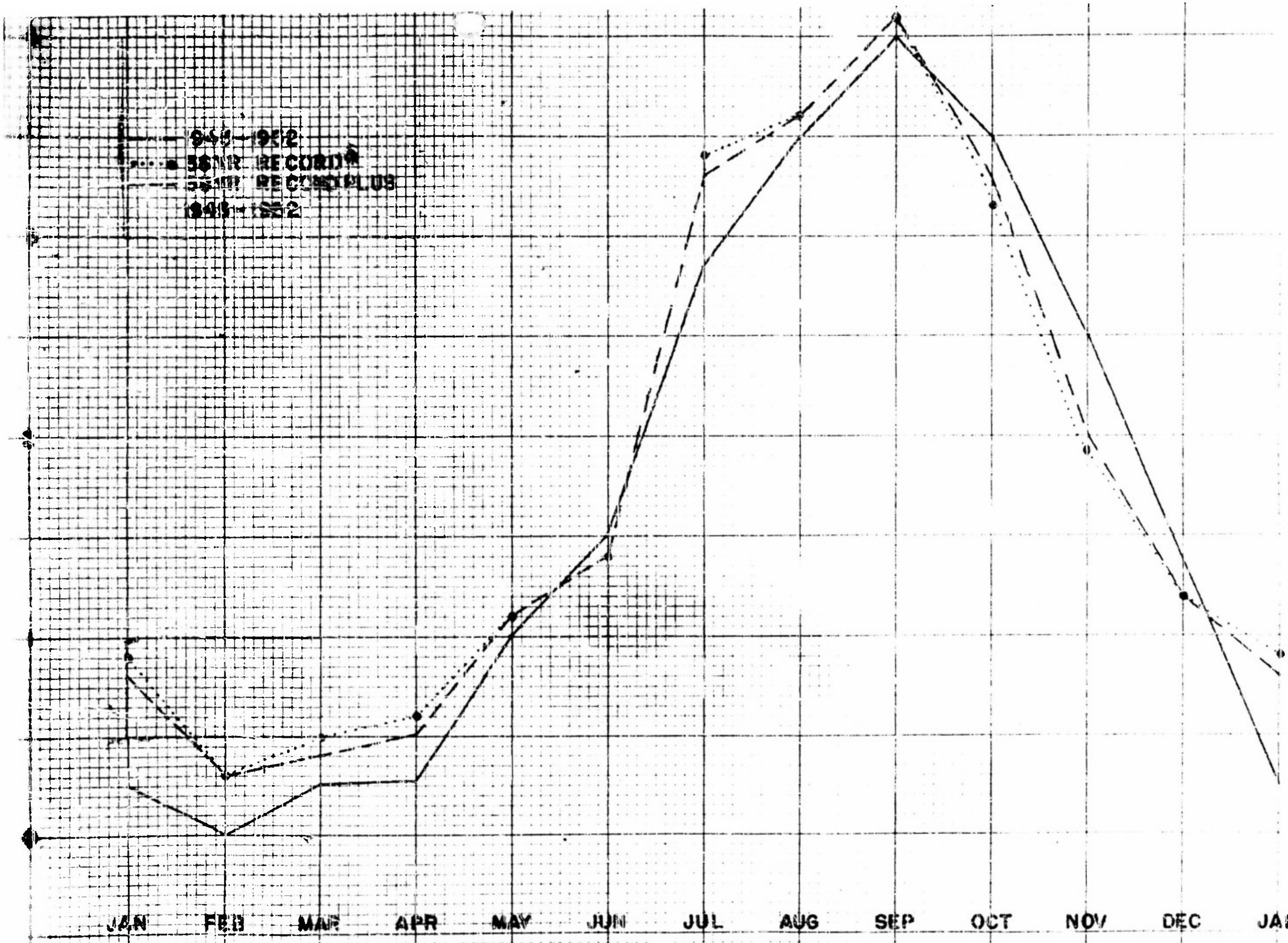
Figure 16 shows the comparison of the mean and monthly percentage distribution for selected periods. The close agreement between the data for the 38 seasons and the 1945-1952 seasons (Figure 17) appears to indicate that there has been no noticeable increase in the number of typhoons or tropical storms developing or being detected during the past 8 year period. Actually the comparison is strictly numerical, and in reality they cannot be closely compared since it is not possible to determine what category or categories of tropical cyclones were included in the 38 year period. In any event the similarity of the graphs is interesting and probably indicates just what it appears to indicate.

Figure 15 gives a complete breakdown of the distribution and frequency of tropical storms and typhoons by months for the years 1945 thru 1952. The figures represent the total number of tropical storms or typhoons detected during the month. The letter following this number indicates whether the systems were tropical storms (S) or typhoons (T). When there were both tropical storms and typhoons included in the first figure, the number of typhoons and tropical storms is entered in parenthesis following the first figure. The remainder of the chart is self-explanatory.

MONTHLY MEAN DISTRIBUTION
OF TROPICAL CYCLONES
AS COMPARED TO 1952
SEASON

MONTH	38 Yrs Record		1945-1952		38 yrs + 8 yrs		1952	
	Mean	%	Mean	%	Mean	%	No.	%
January	.9	4.0	.25	1.1	.8	3.6		
February	.4	1.8	.00	0	.3	1.5		
March	.5	2.2	.25	1.1	.4	2.1		
April	.6	2.6	.25	1.1	.5	2.4		
May	1.1	4.9	1.00	4.8	1.1	4.9		
June	1.4	6.1	1.50	7.2	1.4	6.4	3	11.1
July	3.4	15.5	2.88	13.8	3.3	15.0	3	11.1
August	3.6	16.2	3.50	16.7	3.6	16.2	5	18.5
September	4.1	18.4	4.00	19.0	4.1	18.5	3	11.1
October	3.2	14.4	3.50	16.7	3.3	14.7	6	22.2
November	1.9	8.5	2.50	11.9	2.0	9.1	3	11.1
December	1.2	5.4	1.38	6.6	1.2	5.6	4	14.9
TOTAL	22.3		21.0		22.0		27	

FIG 16



"WEATHER AND CLIMATE OF CHINA", REPORT NO. 890, WEATHER DIVISION, HQ. AAF, MARCH 1945

FIG 17

ESTIMATION OF TYPHOON INTENSITIES

The lowest pressure in a typhoon has been accepted as one of the indices by which the relative "intensity" of the system is measured. It is academic whether the center of lowest pressure is recorded in the center of the eye (as in the model) or is displaced some distance in the direction of movement from the center of the eye (as reports suggest).

However, it has been observed that some typhoons decrease in "intensity" as they move to more northerly latitudes, although, the central pressure remains the same or possibly decreases. We are then forced into the position of defining the intensity of a typhoon in terms of the maximum surface wind speeds. An Air Force installation, a city in the Philippines, a tropical island, or a naval vessel is not affected by a sea level pressure of 975 millibars, per se, but each of these may very well be seriously affected by 100-knot winds.

A very small percentage of typhoons pass directly over a series of weather observing stations. Therefore, we rely almost exclusively upon aircraft weather reconnaissance to determine the actual location and intensity of a typhoon. In a reconnaissance penetration, the sea level pressure is one of the parameters which can be measured accurately without introducing the variability of human estimations. This is not true of the measurement of surface wind speeds.

The Board has no quarrel whatsoever with the estimations made by aircraft weather observers in the past two years; certainly, their es-

timations are well within the accuracy required by the warning service. In fact, forecasts based upon wind fields described by reconnaissance have borne out very satisfactorily when checked against land station anemometer reports. The fact remains, however, that on reconnaissance penetrations, the surface wind speeds are estimated by human observers and are subject to some variability.

In an attempt to develop a more objective method in wind speed estimations, a plot was made of 230 cases of typhoon penetrations in which minimum pressure and maximum winds were both reported. The data considered were selected from GEORGIA of 1951 through HESTER of 1952. More data are available from penetrations in 1950 and previous years. The last two years were studied because it is felt that typhoon reconnaissance observations in this period have reached a higher level of reliability. Further, the number of cases considered is ample to show some interesting and consistent relationships.

Difficulty arose in plotting winds which were reported to be "in excess of 100 knots". Eliminating these reports, the resulting scatter diagram assumed significance. Firstly, it was clear that one curve would not satisfy all points. Secondly, it was obvious that there was a direct relationship between the estimated maximum surface wind speed and the recorded lowest sea level pressure providing the third variable of latitude were introduced.

Various formulae have been suggested to relate the maximum winds and lowest pressure. K. Takahashi [1] recently discussed the empirical

1 "Techniques of the Typhoon Forecast in Japan," paper presented at the Third Annual Typhoon Conference, Tokyo, February 1952.

formula: $V_{max} = 11.5\sqrt{1010-Pc}$ where Pc is the central pressure and Vmax is in knots. Dr. Robert D. Fletcher[2] brought the attention of the Board to the more commonly accepted relationship of $V_{max} = 16\sqrt{1000-Pc}$

In checking a plot of these curves with the actual reconnaissance figures, it appears that the latter is more accurate and best fits the observations which were made on penetrations near 30 N latitude.

Using this as a starting point, various curve fitting attempts were made in which the cosine function of the latitude was used as a factor to compensate for the observed decrease in maximum winds as the typhoon moved poleward with unchanged central pressure. The variation of the cosine or the square of that function does not contribute a rapid enough change to allow the compensation required by observations.

Finally, a refinement of the original formula was established such that the governing factor decreased linearly with an increase in latitude. This family of curves fit the observed data more closely than any previously considered. A plot of this family of $V_{max} = (20 - \frac{\phi}{5})\sqrt{1010 - Pc}$ is seen in Figure 18.

As reconnaissance experience increases, the trend seems to be toward the complete employment of 700 millibar level penetrations on all systems of typhoon intensity. Often during 700 millibar penetrations, the height of that surface is transmitted immediately with the location of the eye. Thirty to forty-five minutes later in the full eye message, the forecaster receives the sea level pressure information as determined

2 AWS sponsored consultant visit to Guam in July 1952.

by dropsonde. It may be two to four hours later after the typhoon has been boxed that the forecaster has a clear picture of the wind field and the maximum wind speed is reported. Since time is of the essence in any warning service, it is evident that the forecaster must have some other tool by which he can immediately ascertain the "intensity" of the typhoon from the information he receives from the weather observer in high level penetration.

Since it is believed that all typhoons develop in a homogeneous air mass, it is reasonable to assume that, thermodynamically, typhoons should be similar to each other (the variations being only in intensity). That is to say, one would expect that if a 700 millibar height of 7500 feet were recorded on penetrations of two different typhoons, the surface pressure computed by dropsonde on both should be similar.

To check the validity of this reasoning, a plot was made of all cases in which 700 millibar height and sea level pressure were both recorded during the period of typhoon penetrations as mentioned above (GEORGIA 1951 through HESTER 1952). A total of 164 cases were plotted. A copy of this graph is seen in Figure 19. Inspection shows that with a very small standard deviation, the best fitting curve is a straight line such that for a decrease of one millibar in surface pressure the 700 millibar height is 28 feet less.

In Figure 20, a working table is presented showing the latitudinal variation of maximum winds empirically determined. It is strongly

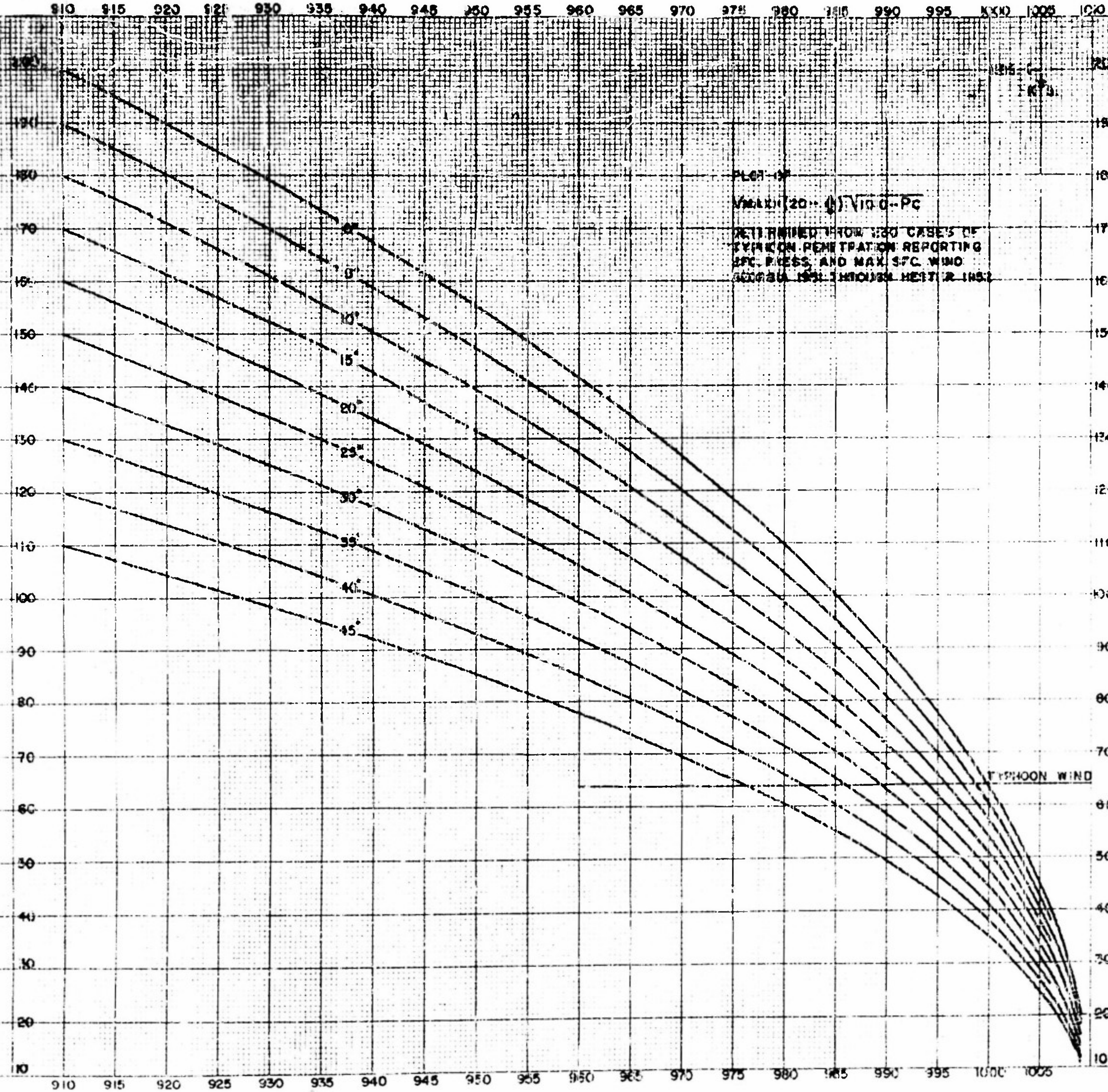

0°
5°
10°
15°
20°
25°
30°
35°
40°
45°
TYPHOON WIND
SFC. PRESS. AND MAX. SFC. WIND

FIG 18

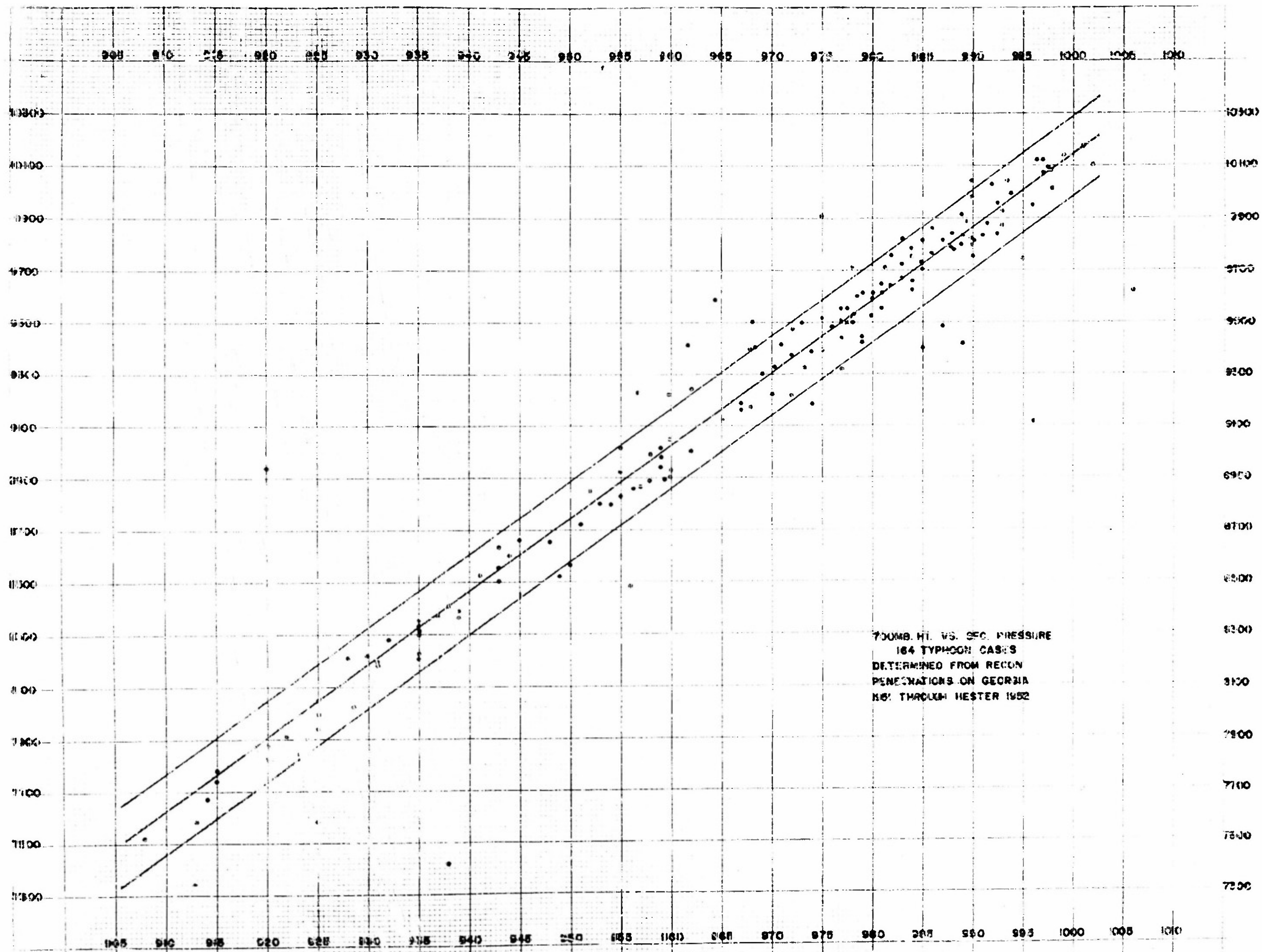

700MB. HT. VS. SFC. PRESSURE
164 TYPHOON CASES
DETERMINED FROM RECON
PENETRATIONS ON GEORGIA
THROUGH HESTER 1952

FIG 19

LATITUDINAL VARIATION OF MAXIMUM WINDS

SFC PRESS	700 MB. HEIGHT	MAXIMUM SURFACE WIND								
		5°	10°	15°	20°	25°	30°	35°	40°	45°
1000	10130	60	57	54	51	48	45	41	38	35
995	9990	74	70	66	62	58	55	50	47	43
990	9850	85	80	76	72	67	63	58	54	49
985	9710	95	90	85	80	75	70	65	60	55
980	9570	104	99	93	88	82	77	71	66	61
975	9430	112	107	100	95	89	83	77	71	65
970	9290	120	114	107	101	95	89	82	76	70
965	9150	128	121	114	108	101	94	87	80	74
960	9010	135	127	120	113	106	99	92	85	78
955	8870	141	133	126	119	111	104	96	89	82
950	8730	148	140	132	124	116	109	101	93	86
945	8590	153	145	137	129	121	113	105	97	89
940	8450	159	151	142	134	126	117	109	101	92
935	8310	165	156	148	139	130	121	113	104	95
930	8170	170	161	152	143	134	125	116	107	98
925	8030	175	166	157	147	138	129	120	111	101
920	7890	180	171	161	151	142	133	123	114	104
915	7750	185	175	165	156	146	137	127	117	107
910	7610	190	180	170	160	150	140	130	120	110
905	7470	195	184	174	164	153	143	133	123	113
900	7330	199	189	178	168	157	147	136	126	115

FIG 20

recommended that reproduction of this table not be made lest it be shown to be in error at the limits by observation and suffer the same fate as most "authoritative" information about typhoons. Admittedly, the danger of this should be less since this table is unique in that it is based on data. The table should be checked for several seasons and refined as necessary before acceptance is granted. In no case should this table be used as evidence to refute subsequent observations.

ON EASTERLY WAVES IN THE PACIFIC

Loyd G Starrett[1]
Major, USAF

Abstract:

Easterly waves are described as they appear in the Pacific within the approximate limits 5N to 15N, 130E to 180E. The description is based on observation and experience in postanalysis, using very limited data. Each of the common meteorological variables is discussed briefly in its relation to easterly waves.

The Easterly Wave Program of the 2143d Air Weather Wing is described in general terms and its primary purpose presented.

Introduction:

This paper is a simple description of observation, which has been reduced to writing in the hope that it will provoke further investigation. It reports no final results of scientific inquiry and offers no voice of authority. The ideas presented are based partly on unorganized experience and partly on the beginnings of research by the Typhoon Postanalysis Board, Anderson Air Force Base, Guam.

In this paper, the term "Easterly wave" will mean a wave-like perturbation, moving in a westerly direction, in the trade winds within the area 5N to 15N, 130E to 180E. It is not implied that either easterly waves or trade winds are confined to such geographic limits, but only

1 Major Starrett is currently with the Severe Weather Warning Center, Tinker AFB, Okla.

that this was the area observed.

Easterly waves will be compared to temperate latitude fronts in several ways in the following paragraphs. This will be done not because these phenomena are similar, but rather in order to associate the observed characteristics with something more familiar, which is psychologically sound.

Movement and Continuity of Easterly Waves:

Most forecasting, and even much of analysis, consists of extrapolation of the known movement of known perturbations or variation in various meteorological elements. Good analysts so locate fronts that their movements appear rather regular and steady. Even so in the tropics, easterly waves move at various speeds, persisting for several days and progressing from east to west at quasi-uniform rates. In the absence of other information, the forecaster will apply the climatological average of ten knots, but as soon as two fixes are obtained, it is usually better to forecast persistence of the speed determined by them. Normally, the trade winds themselves blow at 15 to 30 knots, with very little vertical shear. Thus, easterly waves move at speeds approximating one half the gradient wind speed.

Just as fronts in mid-latitudes often seem to come at semi-regular intervals, so easterly waves have a sort of rhythm, usually passing a station at intervals of about 35 hours. However, most waves are too weak and the rhythm too irregular for it to be a real aid in practical forecasting.

Wind Pattern:

The wind veers with the passage of an easterly wave, though it frequently becomes so variable in the neighborhood of the wave that the time of passage is hard to fix. Sometimes the wind, especially below 3000 feet, backs to a more northerly direction and sometimes it veers briefly 12 to 24 hours before the wave crest passes. When the latter happens at both high and low levels, it becomes practically impossible to determine the wave's tilt from the vertical. Then, too, there are no known limits for the layer containing the wind shift. It varies with time and space, so that a wave that shows strongly at the surface at one station, often lifts to affect only the circulation above 4000 feet at the next. The upper limit of the wind shift is even more variable, ranging upward from 6000 feet. The shift or lack thereof, over 25000 feet is probably of no importance. The vagueness and indecision of this wind pattern, while not greater than for fronts, is more distressing because data are more rare in the tropics and easterly waves exhibit fewer indices for recognition than do fronts.

Orientation and Extent:

Easterly waves are probably oriented nearly north-south, or perpendicular to the direction of the trades. Actually, data are too sparse to reliably fix either the orientation or the latitudinal extent, but apparent speeds between stations of differing latitudes indicate little variation from the north-south assumption. The variation in

effect on the various stations, whose latitudes vary from 6.8N to 13.5N, also indicates a very limited latitudinal extent, probably around 200 to 400 miles in length. These limits are speculative and must remain so until proper air reconnaissance is made. However, it is known that easterly waves pass Eniwetok without having shown a passage at Kwajalein and vice versa.

Easterly waves are usually embedded in the trade stream without affecting the doldrums. However, occasionally there arises a bit of evidence that a wave has extended to the edge of the trade stream (alias Intertropical Front, alias Intertropical Convergence Zone), meeting the doldrums and perhaps setting off a vortex with typhoon-sized potentialities.

Pressure and Its Tendency:

Pressure and pressure tendencies seem to be entirely independent of easterly waves in the area described. Of course, it must be admitted that many of the kinks in isobars at fronts in temperate latitude analyses have a painfully forced look. Yet, fronts do lie in pressure troughs, whereas, even with diurnal variations removed, easterly waves seem to occur about as frequently with rising pressure tendencies as with falling, at maxima as at minima. Neither is any relation between hydrometeors and pressure evident.

Cloud and Precipitation Patterns:

Cloud and precipitation patterns vary widely from front to front and

from easterly wave to easterly wave. The area of increased cloudiness and showers may precede, straddle, or follow the windshift. The size, shape, and degree of homogeneity of this area are unknown, but a rough guess might be somewhat oval, 50 to 200 miles wide, 100 to 400 miles long, with the long axis orientated more or less north-south. Within this area, cumulus and perhaps middle clouds cover 5/10 to 9/10 of the sky, cumulus bases are lower and tops higher than in the environment showers are heavier, more frequent, and last longer. Cirrus has no apparent connection with easterly waves. The reader should be warned that other systems with different movements seem to cause similar weather patterns in the tropics and this pattern should never be used as the sole criterion of an easterly wave passage.

Other Variables:

Easterly waves offer nothing comparable to the air density discontinuity expected across a front. Visibility, surface and upper air temperatures and dew points offer no help in easterly wave analysis. Importance is attached to the "trade inversion" in the Caribbean and eastern Pacific, but this feature is lacking in the Kwajalein-Guam area. Isentropic analysis has shown some relation between the equivalent potential temperature and easterly waves, but it has not yet led to improved forecasting. In fact, differences in both sensible and dew point temperatures are usually insignificant by airmass standards. Easterly waves appear to be vertical, lean forward, or lean backward

without rhyme or reason, without relation to the associated patterns of hydrometeors, and without affecting the motion of the wave. Thus, forecasters find far fewer significant variables in the tropics than in the temperate zones.

There appear to be recognizable diurnal variations in low cloud cover and perhaps in wind. These are quite small, however, and should cause no confusion with easterly wave passages. The probable sizes of these variations are less than 1/10 for low cloud cover, three degrees and two knots for wind.

Areas of Formation and Dissipation:

Just as fronts run the gamut from vigorous wet to weak dry, so do easterly waves. No rules are offered for generation and degeneration, but most waves found in or near the Phillippines can be traced back at least to Kwajalein, which is the eastern edge of routine data. The apparent intensity of the perturbations varies greatly along such tracks, so that careful scrutiny is often necessary to trace a wave through the entire region and achieve continuity. Now, it is admitted that many errors have been perpetrated and perpetuated in the name of continuity, but on the other hand, premature dissipation on the map sometimes results in unforecast storms striking populated areas. This problem of intensification of seemingly extinct systems is common to all forecasting in all latitudes. The best rule is to carry perturbations until rather positive evidence of dissipation is found. Such positive evidence is

furnished by the dense network of reporting stations in the Philippine Islands and shows that many, possibly most, easterly waves dissipate east of these islands, even when the trade winds extend farther west. Other waves are expected to dissipate when they reach the end of the trade stream. However, from time to time, it does appear that perturbations of some sort weaker than typhoons cross boundaries, for example, from doldrums to trade stream, from trade stream to monsoon, and from easterly trades to temperate westerlies.

The Easterly Wave Program:

Forecast Bulletins Pacific (FBPA) are the blood of the Easterly Wave Program of the 2143d Air Weather Wing. These bulletins are issued twice daily and serve two main pruposes. They permit an interchange of opinions and information between stations, partly compensating for the paucity of data in the region, and they focus attention on perturbations that may develop into typhoons. In addition, the Typhoon Postanalysis Board is charged with research on easterly waves and may someday bring new knowledge to bear on this so poorly understood weather system.

STATUS REPORT OF OBSERVING STATIONS

Since the establishment of the Typhoon Annual Reports in 1948, a section has been reserved for "Recommendations for the Improvement of Weather Service Observing and Forecasting Relative to Tropical Cyclones." All of the reports dealing with this section have been authored by typhoon forecasters. Quite naturally therefore, the result has been a devotion to a discussion of forecasting tools. To the knowledge of the Board, nothing has been proposed for the improvement of the observing facilities. In fact, the value and representativeness of the observations has not been considered.

When a forecaster in the Tropical Pacific first comes up against the problem of detecting and forecasting the future movement and intensity of a typhoon his reaction is that of frustration. He may have excellent tools sharpened for application; he may have a thorough understanding of the physical relationships and thermodymatic structure of the tropical atmosphere; however, he is appalled by the lack of data.

It has been suggested in many previous Annual Reports and at all of the Typhoon Annual Conferences that we are on the threshold of great discoveries in typhoon forecasting. All that is needed is more data. The Board does not feel that typhoon forecasting would improve appreciably as the result of additional data; it is obvious, however, that a greater understanding of what is taking place synoptically would be manifest.

An attempt has been made during the 1952 season to gather and assemble information of prime importance to tropical forecasters which

is not available in the International Meteorological Organization Publication No. 9 or the United States Navy Hydrographic Office Publication No. 206. Some information has been gained concerning a total of 47 stations in the tropical region known as Micronesia. Of the 47 stations, 33 have assigned International Meteorological Index Numbers. Seventeen of these are presently taking some form of surface observations; 12 are taking some form of upper air observations; only 3 stations in this entire area are taking complete twenty-four hour surface and upper air observations.

The area included in this survey encompasses all of the Islands in the Ellice, Gilbert, Marshall, Caroline and Marianas Groups and includes 4 Islands which are not attached to any group. This area is approximately six million square miles and constitutes what might be accurately described as the "Birthplace of Typhoons."

Members of the Board have had the opportunity in the past two years to visit all of the stations which are now (March 1953) taking observations in the Tropical Pacific with the exception of the three stations in the Ellice Island Group and Beru in the Gilbert Island Group. In Figure 21 a summary of this information is presented in tabular form. The summary includes not only all of the pertinent geographic and physical information but also the schedule of observations and transmission routing. The considered opinion of the value of these observations is also included in the summary.

Because the recent history of Micronesia has entertained influences of the Germans and Japanese as well as the Americans, it is sometimes difficult to find two maps which agree on the location or even the names

of some of the Islands. Therefore, a supplementary table has been prepared (Figure 22) showing the presently accepted station name and those alternate names which have been found on other maps or in literature. For example, Truk has been known as "Ruk", "Torakku" and "Hogolen" in the past 50 years. (The observations at Truk are actually made on the Island of Moen in the Truk Group).

Island Classification

Generally speaking, the Islands in Pacific Micronesia can be classified as either of an Atoll type or Basalt type. All of the Islands in the Ellice, Gilbert, Marshall and part of the Eastern Carolines are of the Atoll type, i.e., smaller Islands located on a surface reef, surrounding s shallow lagoon and surrounded by the deep ocean. The maximum height of any Island in this class is nineteen feet on Roi Island in the Kwajalein Atoll. Of course the coconut trees extend several hundred feet above the Island in some cases. The coconut trees on the Kapingamarangi are equal to the height of the Giant Sequois in California.

Those Islands in the Central and Western Caroline Group and all of the Islands in the Marianas Group are of the Basalt formation, i.e., the principal Islands extend to considerable altitude inside a nearly circular reef. The highest point in this type of Island is 2576 feet on Ponape. All of the Islands in this class extend over 500 feet in height.

The only exception to these two classes of Islands are the detached Islands of Nauru and Ocean, located 500 miles South of Kwajalein. These

NETWORK OF TROPICAL OBSERVATIONS

AS OF MARCH 1953

1. STATION	WAKE	KWAJALEIN	ENIWETOK	ANDERSEN	NAS AGANA	SAIPAN*
2. ISLAND	WAKE	KWAJALEIN	ENIWETOK	GUAM	GUAM	SAIPAN
3. GROUP	DETACHED	MARSHALL (Ralik)	MARSHALL (Ralik)	SOUTHERN MARIANAS	SOUTHERN MARIANAS	CENTRAL MARIANAS
4. INTERNATIONAL METEOROLOGICAL INDEX NUMBER	91245	91366	91250	91218	91212	91232
5. ISLAND ELEVATION	21	19	17	1334	1334	1554
6. STATION ELEVATION	10	7	15	530	267	[illegible]
7. STATION LOCATION	Terminal building about ½ mi north of east tip of runway. (Before OLIVE)	Quonset building SE end of runway	Aluminum building SW end of runway.	Operations building south of middle of runway; 570 ft hill 1 mi SE; station located on plateau at NE tip of island.	Operations building south of middle of runway; 1076 ft hill 5 mi SW; 1334 ft hill 11 mi SW; 744 ft hill 2 mi East; station near island center.	Part of Loran Station Building 1 mi S of Kobler Field. No site or hill visibility est.
8. EQUIPMENT STATUS	Good (Before OLIVE)	Good	Excellent	Good	Good	Being Replaced
9. OBSERVER STATUS	U.S. Weather Bureau personnel	U.S. Naval personnel	U.S.A.F. personnel	U.S.A.F. personnel	U.S. Naval personnel	U.S. Coast Guard personnel not trained [illegible]
10. OBSERVATIONS a. Surface	MT ALL TH ALL AW ALL	MT ALL TH ALL AW ALL	MT ALL TH ALL AW ALL	MT ALL TH ALL AW ALL	MT ALL TH ALL AW ALL	MT 00,06 TH 03,09,21 AW None
b. Upper Air	PB ALL RB ALL	PB ALL RB 03,15	PB ALL RB ALL	PB ALL RB ALL	PB 03,21	No obs include cloud types or heights None
11. TRANSMISSION ROUTING TO BROADCAST	All Obs to CAA Guam (KGUM); all except AW retransmitted via island "3128" circuit to broadcast center	All Obs direct to broadcast center over radio teletype circuit "TR315"	All Obs except AW direct to Kwajalein (KKWA) thence to broadcast center over circuit "TR315"	Direct to broadcast center over island "3128" circuit.	PB ( ) direct to broadcast center over island "3128" circuit. All other Obs receive island distribution only on KGUM collectives	Via radio circuit to USCG Guam thence to Navy Comm Center (NMPC) for island distribution only.
12. TRANSMISSION OVER BROADCAST	On all appropriate LAND collectives except AWPA FAX	On all appropriate LAND collectives	On all appropriate LAND collectives except AWPA LAND	On all appropriate LAND collectives	On FBPA LAND OCOCP collective only	Not Retransmitted
13. EXPOSURE	EXCELLENT	EXCELLENT	EXCELLENT	GOOD	FAIR	FAIR
14. REPRESENTATIVENESS OF DATA						
Pressure	YES	YES	YES	YES	YES	NO
Temperature	YES	YES	YES	NO	NO	YES
SFC Wind Direction	YES	YES	YES	VERY CLOSE	Very close except when winds are light	Very Close
SFC Wind Speed	NO	YES	YES	5 knots too low all directions	5-15 knots [illegible] all directions	5-10 knots too low all directions
Low Cloud Amts	YES	YES	YES	ALMOST	NO	Not Reported
Low Cloud Heights	YES	YES	YES	ALMOST	ALMOST	Not Reported
Rainfall	YES	YES	YES	ALMOST	ALMOST	Not Reported
Middle Clouds	YES	YES	YES	YES	YES	Not Reported
Upper Winds	YES	YES	YES	From 1000 Ft	From 2000 Ft	Not Reported

1. STATION	TRUK	YAP	PONAPE	PALAU	MAJURO	NAURU
2. ISLAND	MOEN	YAP	PONAPE	KOROR	ROMALIK	NAURU
3. GROUP	EASTERN CAROLINE	WESTERN CAROLINE	EASTERN CAROLINE	CAROLINE (PALAU)	MARSHALL (RADAK)	DETACHED
4. INTERNATIONAL METEOROLOGICAL INDEX NUMBER	91334	91413	91348	91408	91376	91530
5. ISLAND ELEVATION	1483	585	2576	785	12	213
6. STATION ELEVATION	10	57	139	109	6	25
7. STATION LOCATION	Quonset building SE end of runway; 754 ft hill 1 mi east; 1214 ft hill ½ mi east	Small shack overlooking Tomil Harbor; 587 ft hill 2 mi N, 580 ft hill 1 mi NW; 293 ft hill 4 mi NE; [illegible] 2 mi SW (good exposure) abandoned	4th & 5th floor of Agricultural Experimental Sta station in a wire bent surrounded by mountains 2630 ft range 4 mi S to SE and SW	2d floor of former Japan CNO Building atop high hill with ocean front only obstruction to exposure	Reported to radio shack on extreme eastern tip (roof of do) of island; ½ mi north of runway on differ. island	3d floor of British Phosphate Company Administration Building on east side of Plateau; ½ mi 1 of NW end of abandoned runway.
8. EQUIPMENT STATUS	Fair	Good	Good	Fair	Poor	Fair
9. OBSERVER STATUS	U.S. Weather Bureau personnel (at least 2 career observers at each station) paid from funds through agreement with U.S. Navy. Indigenous personnel being trained at each location.				One Indigenous obs paid by U.S. Dept of Interior trained by USWB prior to changeover	Employees of British Phosphate Co; Australian personnel
10. OBSERVATIONS a. Surface	MT 00,06,12 TH 03,15 AW None	MT 00,06,12 TH 03,15 AW None	MT 00,06,12 TH 03,15 AW None	MT 00,06,12 TH 03,15 AW None	MT 00,06,12 TH 03,15 AW None	MT 00,06,18 TH 03,21 AW None
b. Upper Air	PB 03,15 RB 03	PB 03,15 RB 03	PB 03,15 RB 03	PB 03,15 RB 03	None	PB 21 RB None
11. TRANSMISSION ROUTING TO BROADCAST	All obs direct to Naval Communications Center (NMPC) Guam, via CW; thence via administrative land line teletype to Broadcast Center.					Direct to [illegible], Fiji, via CW circuits; thence over [illegible] broadcast, [illegible] collectives received at Sydney and Honolulu CAA; rebroadcast via Sydney on [illegible] collectives; retransmitted from Honolulu under [illegible] collectives to Broadcast Center.
12. TRANSMISSION OVER BROADCAST	ON ALL AWPA LAND COLLECTIVES			ON ALL AWPA LAND COLLECTIVES		ON ALL AWPA SHIP COLLECTIVES
13. EXPOSURE	FAIR	FAIR	POOR	FAIR	EXCELLENT	FAIR
14. REPRESENTATIVENESS OF DATA						
Pressure	YES	YES	1.2 MB too high	1.5 MB too low	NO	YES
Temperature	YES	Probably	NO	YES	YES	NO
SFC Wind Direction	E only	SE only	NO	Very Close	YES	S-SE-E & NE only
SFC Wind Speed	5-10 knots low except when wind E of NE	5-15 knots low except when wind NE	NO	5-15 knots low except when wind E	YES	[illegible] knots too low except when wind [illegible] NE
Low Cloud Amts	Almost	Almost	NO	Almost	YES	NO
Low Cloud Heights	Almost	Slightly Lower	NO	Almost	YES	Almost
Rainfall	NO	Maybe	NO	Maybe	YES	Maybe
Middle Clouds	YES	YES	Maybe	YES	YES	YES
Upper Winds	From 3000 ft	From 1000 ft	From 4000 ft	From 1000 ft	Not Reported	From 1000 ft

1. STATION	TARAWA	BERU	NANUMEA	FUNAFUTI	NUKULAITA
2. ISLAND	TARAWA	BERU	NANUMEA	FUNAFUTI	NUKULAITA
3. GROUP	GILBERT	GILBERT	ELLICE	ELLICE	ELLICE
4. INTERNATIONAL METEOROLOGICAL INDEX NUMBER	91610	91623	91631	91643	91648
5. ISLAND ELEVATION	FROM 1 TO 10 FEET		FROM 1 TO 10 FEET		
6. STATION ELEVATION	ABOUT 5 TO 10 FEET		ABOUT 5 TO 10 FEET		
7. STATION LOCATION	Probably on north tip of extreme SE island of Atoll north of runway of Hawkins Field	Probably southern tip of island	Probably East Central part of island on Lagoon side of runway	Probably SW of runway on Lagoon side	Location Unknown
8. EQUIPMENT STATUS	Unknown	Unknown	Unknown	Unknown	Unknown
9. OBSERVER STATUS	Unknown; believed to be personnel associated with Royal Australian and/or Royal New Zealand Meteorological Services assisted by indigenous personnel.				
10. OBSERVATIONS a. Surface	MT ALL TH 03,21 AW None	MT 00,06,18 TH 03 AW None	MT [illegible],06,18 TH Unknown AW None	MT ALL TH 03,21 AW None	MT Unknown TH 03,21 AW None
b. Upper Air	PB 05,17,23 RB None	None	None	PB 21 RB None	None
11. TRANSMISSION ROUTING TO BROADCAST					
12. TRANSMISSION OVER BROADCAST			ON ALL AWPA [illegible] COLLECTIVES		
13. EXPOSURE	EXCELLENT	EXCELLENT	EXCELLENT	EXCELLENT	EXCELLENT
14. REPRESENTATIVENESS OF DATA					
Pressure	YES	YES	YES	YES	YES
Temperature	YES	YES	YES	YES	YES
SFC Wind Direction	YES	YES	YES	YES	YES
SFC Wind Speed	YES	YES	YES	YES	YES
Low Cloud Amts	YES	YES	YES	YES	YES
Low Cloud Heights	YES	YES	YES	YES	YES
Rainfall	YES	YES	YES	YES	YES
Middle Clouds	YES	YES	YES	YES	YES
Upper Winds	YES	Not Reported	Not Reported	YES	Not Reported

*Observations temporarily suspended.

FIG 21

International Meteorological Index Number	Station Name	Alternate Names	Latitude	Longitude
ELLICE ISLANDS				
91 643	Funafuti		08-31 S	179-12 E
91 631	Nanomea	Nanumea, St. Augustine	05-39 S	176-06 E
91 648	Nurakita	Sophia	10-45 S	179 30 E
GILBERT ISLANDS				
91 604	Maraki	Marakei, Matthews	01-58 N	173-15 E
91 443	Little Makin	Pitt	03-23 N	172-59 E
91 601	Makin	Butaritari, Touching	03-02 N	172-48 E
91 607	Alaiang	Abaiang, Charlotte	01-46 N	173-01 E
91 610	Tarawa	Knox, Cook	01-21 N	172-56 E
91 615	Abemama	Apamama, Hooper, Roger	00-21 N	173-51 E
91 620	Noncuti	Sydenham	00-48 S	174-28 E
91 623	Beru	Francis	01-21 S	175-55 E
None	Bikati		03-11 N	172-42 E
MARSHALL ISLANDS				
Radak (Sunrise) Group				
91 376	Majuro	Medjuro, Madjuro, Arrowsmith	07-05 N	171-23 E
91 254	Rongerik	Radokala	11-22 N	167-31 E
None	Likiep	Count Heiden, Legiep, Lekieb	09-49 N	169-18 E
Ralik (Sunset) Group				
91 366	Kwajalein	Kwadjalin, Menschikoff, Mentschikow	08-43 N	167-44 E
91 363	Roi		09-24 N	167-28 E
91 369	Jaluit	Bonham	05-55 N	169-39 E
91 250	Eniwetok	Brown	11-21 N	162-21 E
None	Ujelang	Ujelong, Arecifos, Providence, Casobos	09-46 N	160-59 E
None	Ailinglapalap	Ailinglapala, Odia, Elmore, Helut	07-16 N	168-50 E
None	Ebon	Boston, Covell	04-04 N	168-42 E
None	Namorik	Baring	05-05 N	168-07 E
None	Bikini	Eschscholtz	11-37 N	165-32 E
CAROLINE ISLANDS				
Eastern Group				
91 356	Kusaie	Ualan, Strong	05-20 N	163-01 E
91 348	Ponape	Ascension, Puynipet	06-56 N	158-12 E
91 334	Truk	Ruk, Torakku, Hogoleu	07-28 N	151-51 E
None	Ngatik	Natikku, Raven	05-50 N	157-11 E
None	Oroluk	Bordelaise	07-08 N	155-09 E
Central Group				
91 317	Woleai	Mereyon, Ulie, Thirteen	07-23 N	143-55 E
Western Group				
91 413	Yap	Yappu	09-31 N	138-07 E
None	Ulithi	Urushi, Uluthi, Mackenzie	10-01 N	139-48 E
None	Ngulu	Kurru, Matelotas, Lamoliork	08-17 N	[illegible] 29 E
Palau Group				
91 408	Koror	Kororu, Korror	07-20 N	134-29 E
None	Angaur	N'gaur, Angauru	06-54 N	134-09 E
None	Palau	Babelthuap, Baberudaobu, Arrecifos	07-30 N	134-38 E
MARIANAS ISLANDS				
91-207	Orote Point	Orote Field	13-27 N	144-38 E
91-211	Agana	Agana	13-28 N	144-44 E
91 218	Andersen AFB	North Field (Guam)	13-35 N	144-56 E
91 212	NAS Agana	Guam	13-29 N	144-47 E
91 232	Saipan	Kobler AFB	15-07 N	145-42 E
91 234	Tinian	Bona Vista, West Tinian AFB	15-00 N	145-37 E
91 215	Harmon AFB		13-31 N	144-49 E
DETACHED ISLANDS				
[illegible] 245	Wake		19-17 N	166-39 E
[illegible] 530	Nauru	Pleasant, Shank, Nawodo	00-32 S	166-55 E
[illegible] 533	Ocean	Banaba	00-52 S	169-35 E
[illegible]	Kapingamarangi	Greenwich	01-03 N	154-48 E

FIG 22

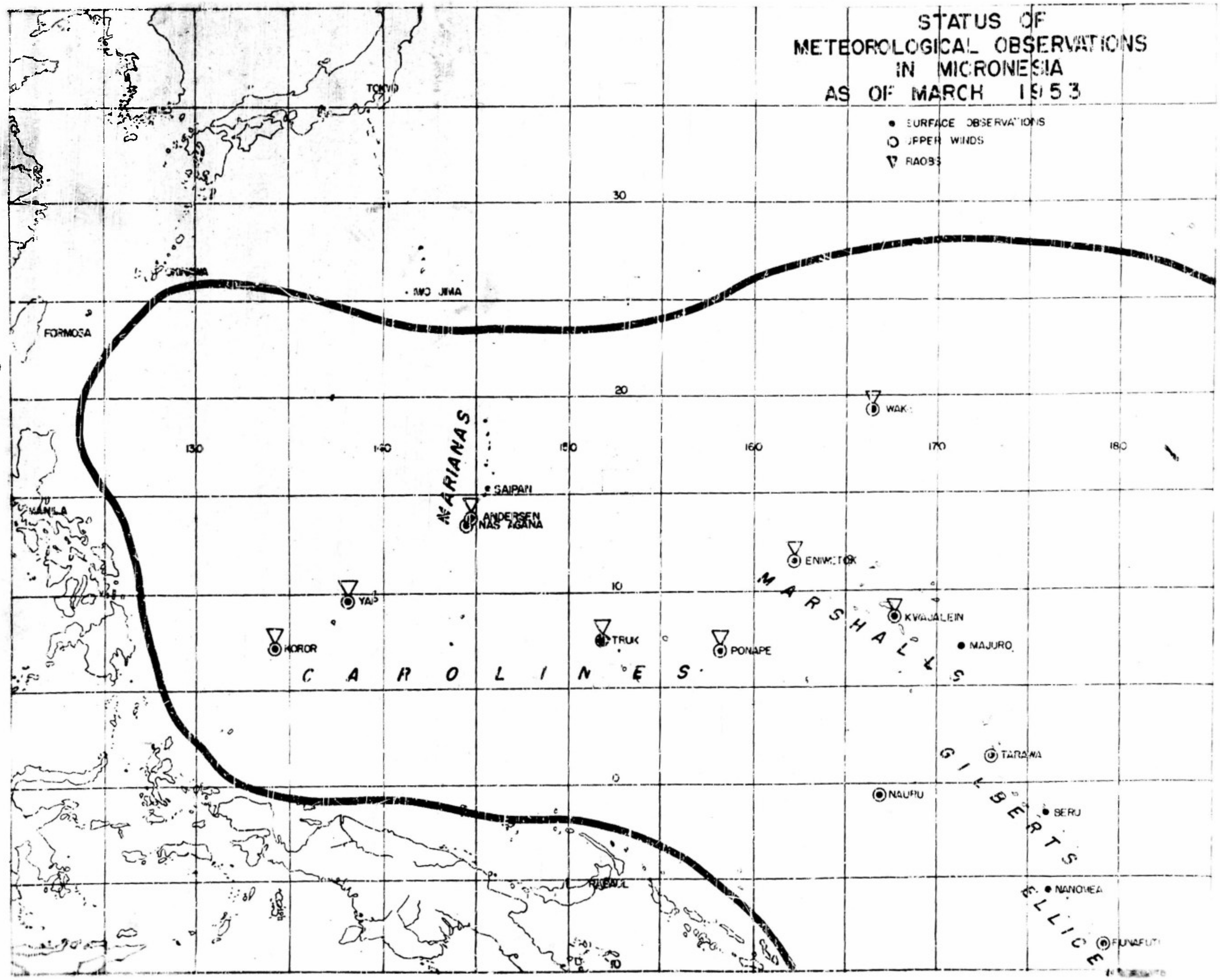

STATUS OF
METEOROLOGICAL OBSERVATIONS
IN MICRONESIA
AS OF MARCH 1953
SURFACE OBSERVATIONS
UPPER WINDS
RAOBS
TOKYO
OKINAWA
IWO JIMA
FORMOSA
MANILA
MARIANAS
SAIPAN
ANDERSEN
NAS AGANA
YAP
KOROR
TRUK
PONAPE
ENIWETOK
WAKE
KWAJALEIN
MAJURO
CAROLINES
MARSHALLS
TARAWA
NAURU
GILBERTS
BERU
NANOMEA
ELLICE
RABAUL
30
20
10
0
10
130
140
150
160
170
180

Fig 23

Islands are nearly 100% phosphate in composition and extend to approximately 250 feet.

It should be obvious that all surface observations taken at Islands of the Atoll class are extremely representative of the weather in the region surrounding the Atoll. Conversely, unless the station is selected with a good exposure, nearly all stations which are located on Basalt-composed Islands cannot make observations which are representative of the atmosphere surrounding the station.

Discussion of Islands by Groups

Ellice Islands: So far as is known to the Board only three stations in this group have ever made weather observations. These stations, Naromea, Funafuti and Nurakita are still taking surface observations at scattered times daily. Funafuti takes a Pibal at 2300Z daily.

Gilbert Islands: In this group there are at least nine stations which have made observations in the past. Presently, only Tarawa in the Northern Gilberts and Beru in the Southern Gilberts are taking observations. Tarawa takes a Pibal at 0500Z, 1700Z and 2300Z daily. Occasionally, Bikati which has no International Index Number has been used as an observation point during atomic testings in the Marshall Island area.

The Gilbert Island Group is a good example of how little accurate information is available about this entire area; Abemama has the Index Number 91454 and Apamama has the Index Number 91615. These are one and the same place. The two names are merely two native dialects. The same is true of Alaiang and Abaiang which have the Index Numbers 91447 and

91607. Bikati has used the Index Numbers 91443 and 91601 which are for Little Makin and Makin Atolls, two separate Islands and both different from Bikati.

Marshall Islands: This Group is divided into two chains of Atolls, roughly parallel, oriented northwest to southeast. The Radak (sunrise) chain has fewer Islands than the Ralik (sunset) chain. Majuro is the only station in the Radak chain taking observations at the present time. The observations are made by one indigenous observer. No upper air observations are available. Rongerik and Likiep were used during the German control, 1875 to 1914.

In the Ralik chain several Islands have been used extensively in the past 75 years. During the German rule, Jaluit was the principal Island and only observation spot. When the Boston Missionary Society moved into the Tropical Pacific, Ebon became another observation point. Menschikoff, now known as Kwajalein, was the site of observations as early as 1894. At the present time only Kwajalein and Eniwetok have weather observing stations. In recent history Bikini, Ujeland and Roi have been used. The Typhoon Warning Service would gain much from the introduction of weather observing stations at strategic locations such as Ailinglapalap. Most of these Island locations do not have International Index Numbers.

Caroline Islands: Observations are presently being taken in this U. N. Trust Territory Group at Ponape, Truk, Yap and Koror. The key station of Kusaie has been used during atomic testing programs in the Marshall

Islands and was a principal station in both the German and Japanese networks in this area. Today a report from Kusaie would have added significance because of the complete unrepresentativeness of the data from Ponape. It would be extremely desirable to have some form of surface observation from Kusaie and in addition, Mokil or Ant Atoll. Ngatik and Oroluk (both Atolls) are also geographically situated to be good points of observations.

In the Central Group of the Caroline Islands, Woleai Atoll, Index No.91317, would be an extremely valuable observation point because of its strategic location with respect to the majority of typhoon tracks.

In the Western Group, reports from Yap are extremely valuable. It is regrettable that the observation point that the Japanese and Germans employed on this Island with excellent exposure has been abandoned. Weather reports are made available upon request from the Coast Guard Unit at Ulithi. It has been suggested that a detachment of weather observers from Fleet Weather Central Guam be assigned to Ulithi for continuous regular observations. Ngulu would be a good location for another possible point.

In the Palau Group, Koror using the Index Number of the station of Palau, 91408, is the only station taking weather observations at present. Its location is such that the observations are reasonably meaningful.

<u>Marianas Islands</u>: On the Island of Guam there have been five separate observation points in the past 10 years. At the present time, Andersen Air Force Base observers take the only observations which are given

Broadcast distribution. Surface observations are also taken at Fleet Weather Central, NAS, Agana. These observations receive distribution on the Island of Guam only. At present there is no activity at Tinian. The observations which were taken at Saipan by Coast Guard personnel have been temporarily suspended. It is planned that observers will be detached from Fleet Weather Central, Guam, to this location during 1953.

It would be desirable to have a weather station located on some Island in the Northern Marianas, either at Pajaros or Maug Island.

Detached Islands: Wake Island, recovered from OLIVE, is still one of the principal stations in the Tropic region. Even if Wake never had aircraft traffic, it should be maintained as a Class A weather observing station. With Eniwetok and Andersen, Wake is one of the three stations in the entire Micronesia which currently take complete twenty-four hour surface and upper air observations.

Nauru and its twin sister, Ocean Island, both under U.N. Trusteeship (Australia), have had observing stations in the past 5 years. At the present time, surface observations are made at Nauru and one Pibal is taken at 2300Z daily. It is believed that this service is provided by the employees of the British Phosphate Company located on Nauru.

Kapingamarangi is situated on the southern boundaries of Micronesia in such a position that the trade routes of the world have never come close to her. It is a completely detached Atoll approximately 1,000 miles Southeast of Guam. Regular weather observations from Kapingamarangi would contribute greatly towards a better understanding of the doldrum

region of the Tropics and give us a better insight into the cross-equatorial relationships in the development of typhoons.

When it is realized that the cost for all salaries, supplies, equipment and maintenance of the Trust Island stations during the last quarter of Fiscal Year 1952 was less than the cost to complete three Vulture Lima Reconnaissance Missions, it would not seem unreasonable to consider the establishment and maintenance of weather observation points at some of the Islands mentioned above.

MONTHLY FREQUENCY TABLE OF TROPICAL CYCLONES BY CLASSES 1945-1952

MONTH	1A	1B	2A	2B	2C	3A	3B	4	X	Total
January	1								1	2
February										0
March							1	1		2
April								1	1	2
May	4					1		3		8
June	3	4	3		2					12
July	1	2	6	1	1			3	9	23
August	1	1	7	2				5	12	28
September	8	2	9	2	4		1	4	2	32
October	4	3	3		2	7		6	3	28
November	5	4	3	1	1	2	3	1		20
December	2		1			5	2	1		11
TOTAL	29	16	32	6	10	15	7	25	28	168
MEAN	3.62	2.00	4.00	.75	1.25	1.88	.88	3.12	3.50	21.00
%	17.1	9.5	19.0	3.6	6.0	9.0	4.2	14.9	16.7	

FIG 14

MONTHLY FREQUENCY TABLE OF TROPICAL CYCLONES 1945 - 1952

MONTH	1945	1946	1947	1948	1949	1950	1951	1952	TOTAL	MEAN
January				1 T	1 T				2	.25
February									0	.00
March		1 T					1 T		2	.25
April	1 S						1 S		2	.25
May	1 S	1 T	1 T	2 T		1 T	2 (1T 1S)		8	1.00
June	2 (1T 1S)	1 T	1 T	2 S	1 T	1 T	1 T	3 T	12	1.50
July	5 (1T 4S)	3 T	1 S	2 T	5 (4T 1S)	3 (1T 2S)	1 T	3 (1T 2S)	23	2.88
August	7 (4T 3S)	2 T	3 T	6 (2T 4S)	2 T	2 T	1 T	5 (3T 2S)	28	3.50
September	5 (3T 2S)	4 (3T 1S)	4 T	5 (4T 1S)	3 T	5 (2T 3S)	3 T	3 T	32	4.00
October	3 (1T 2S)		6 (5T 1S)	4 (1T 3S)	2 T	3 T	4 (3T 1S)	6 (5T 1S)	28	3.50
November	2 (1T 1S)	2 T	5 (3T 2S)	2 (2 T)	2 (1T 1S)	3 (2T 1S)	1 T	3 T	20	2.50
December			1 T	1 T	2 T	1 T	2 T	4 T	11	1.38
TYPHOONS	11	13	18	15	16	13	14	22		15.25
STORMS	15	1	4	10	2	6	3	5		5.75
TOTALS	26	14	22	25	18	19	17	27	168	21.00

FIG 15